THE COMPOSITION AND STRENGTH OF MORTARS

W. J. DIBDIN

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THE COMPOSITION AND STRENGTH OF MORTARS

REPORT ON THE RESULTS OF THE EXPERIMENTAL INVESTIGATION CONDUCTED FOR THE SCIENCE STANDING COMMITTEE OF THE ROYAL INSTITUTE OF BRITISH ARCHITECTS

BY

W. J. DIBDIN, F.I.C., F.C.S., ETC.

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SECTION I

INTRODUCTION

In accordance with the Scheme of Procedure adopted by the Science Standing Committee of the Royal Institute of British Architects on November 14, 1907, which I attach hereto, signed by the Chairman Mr. Lewis Solomon, the extensive series of experiments detailed therein has been completed, and I now have the honour of submitting for the consideration of the Committee the results as set out in the following tabulated statements, and observations on the conclusions deduced therefrom.

For greater facility in comparison diagrams have been prepared of all the principal factors, and these accompany the tables.

The work involved—

1. The collection and examination of representative samples of materials, viz. limes, sands and bricks.

2. The preparation from these of—

828	briquettes for tensile strength.
828	blocks for crushing ,,
120	pairs of bricks for adhesive strength, making
1776	experiments in all.

3. The design and construction of special modifications to the compound lever cement testing machine for the purpose of effecting the crushing and adhesive tests. The method previously employed permitted only a pressure of 500 lb. per square inch for the crushing strength, which was ample for ordinary mortars but insufficient for the present purpose, and by the kindness of Mr. G. E. Moore, M.Inst.Mech.E., who designed and constructed the exceedingly convenient and effective modifications in the machine described at length in the note attached, all difficulties on this point were overcome.

The adhesive test was also facilitated by Mr. Moore's assistance—and his construction of the necessary adjunct to the same machine.

At first, as reported to your Committee on July 27, 1908, Prof. J. D. Cormack, of University College, London, kindly granted the use of the large testing apparatus in his laboratory for the purpose of the experiments, but it was at once found on trial that the machine was unsuitable in consequence of its size and power, and it became necessary to design a more simple method, and I desire to acknowledge my indebtedness to Mr. Moore for his invaluable aid.

4. As an auxiliary to the foregoing a series of mortars from ancient buildings has been kindly forwarded to me for analysis by members of your Committee, who thereby have enabled me to place on record the results of the chemical and physical examination of a number of authenticated samples of representative mortar of variable qualities, which, having stood the test

of time, supply a valuable means of comparison with the series specially prepared and tested in connection with the present investigation.

5. The tabulation of all results, preparation of diagrams, and discussion of the experimental factors.

6. After the tests sanctioned by the Committee had been commenced it was contemplated to add a further series in connection with trass and pozzuolana; but it was soon realised that the work already in hand rendered it impossible, under the existing circumstances, to extend it at that time. Fortunately, however, this was a matter of minor importance in view of the excellent series of tests with trass that had been undertaken in Germany by government engineers, in connection with public works; which tests, by the courtesy of Mr. William Challoner of Blackpool, I am enabled to add to this Report. The use of trass, a volcanic calcined clay, is an important industry on the Continent; the output from the Tuffstein quarries at Krufft and at Kreutz, both in the Nette Valle near Andernach on the Rhine, is stated to be over 200,000 tons per annum, being used for German, Belgian, French, and Dutch engineering and building works. This large application is principally owing to the result of research work and experiments carried out by the Commission on Building Materials which has existed for the past twenty-five years under State subsidy in connection with the Government Experimental and Testing Institute at Charlottenburg. In consequence of the information thus placed at their disposal, the German State Railway and other departments have recently adopted standard specifications for mortars and concretes, which have been extracted from a paper on "The Use of Trass for Mortars and Concretes in Modern Building Construction," read at the sectional meeting of the National Association of Technical Engineers of Germany, by M. J. Mund, Cologne, in 1908.

The samples of chalk lime, and of sand, were kindly supplied by Messrs. Hall & Co. Ltd., Croydon, and the blue lias lime was forwarded by Messrs. Chas. Nelson & Co. from their works at Stockton, Rugby. The stock bricks were supplied by Mr. W. Willett from the Brickfields, Langley, Bucks, and the Fletton Bricks by the Fletton Crown and Crowhurst Brick Co. Ltd. To all these firms my acknowledgment is due and hereby tendered for the facilities thus courteously afforded me. The ground grey Kent stock brick, as commonly used in London buildings, and red London clay were kindly arranged for by Mr. H. D. Searles-Wood, a member of your Committee.

I have to acknowledge the assistance rendered in connection with this investigation by my son, Mr. F. J. A. Dibdin, who was largely engaged in connection with the former investigation, the results of which I had the honour to submit to the Royal Institute in December 1906, and who thus commenced the present work with no little experience. With the help of Mr. Leonard Cooper, F.C.S., etc., and Mr. Wilfred Corry, Mr. F. J. A. Dibdin prepared the whole of the testing briquettes, blocks, etc., and also assisted in connection with the alterations to the testing machine, as well as with the breaking and crushing tests at the respective periods.

A. WHITE CHALK LIME (95 per cent. CaO)

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
With Standard Sand (*Leighton Buzzard*).								
1 Lime 2 Sand	——	——	——	——	——	——	——	——
,, ,,	——	——	——	——	——	——	——	——
,, ,,	——	——	——	——	——	——	——	——
1 Lime 3 Sand	——	——	——	——	——	——	——	——
,, ,,	——	——	——	——	——	——	——	——
,, ,,	——	——	——	——	——	——	——	——
1 Lime 4 Sand	——	——	——	——	——	——	——	——
,, ,,	——	——	——	——	——	——	——	——
,, ,,	——	——	——	——	——	——	——	——
1 Lime 5 Sand	——	——	——	——	——	——	——	——
,, ,,	——	——	——	——	——	——	——	——
,, ,,	——	——	——	——	——	——	——	——

Repeat above with—

Fine Sand (Charlton)

Pit Sand (Ordinary)

Thames Sand

Ground Brick

(Grey Kent Stock, not over-burnt, as commonly used in London buildings)

= 240 briquettes

240 blocks

LEWIS SOLOMON, *Chairman.*

14.11.07.

B. DORKING GREYSTONE LIME

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
With Standard Sand (*Leighton Buzzard*).								
1 Lime 2 Sand	—	—	—	—	—	—	—	—
,, ,,	—	—	—	—	—	—	—	—
,, ,,	—	—	—	—	—	—	—	—
1 Lime 3 Sand	—	—	—	—	—	—	—	—
,, ,,	—	—	—	—	—	—	—	—
,, ,,	—	—	—	—	—	—	—	—
1 Lime 4 Sand	—	—	—	—	—	—	—	—
,, ,,	—	—	—	—	—	—	—	—
,, ,,	—	—	—	—	—	—	—	—
1 Lime 5 Sand	—	—	—	—	—	—	—	—
,, ,,	—	—	—	—	—	—	—	—
,, ,,	—	—	—	—	—	—	—	—

Repeat the above with—

Fine Sand (*Charlton*)

Pit Sand (Ordinary)

Thames Sand

Ground Brick (see "A")

= 240 briquettes,

240 blocks.

LEWIS SOLOMON, *Chairman.*

14.11.07.

C. BLUE LIAS LIME FROM NELSON'S, STOCKTON, NEAR RUGBY

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
With Standard Sand (*Leighton Buzzard*).								
1 Lime 2 Sand								
,, ,,								
,, ,,								
1 Lime 3 Sand								
,, ,,								
,, ,,								
1 Lime 4 Sand								
,, ,,								
,, ,,								
1 Lime 5 Sand								
,, ,,								
,, ,,								

Repeat above with—

Fine Sand (*Charlton*)

Pit Sand (Ordinary)

Thames Sand

Ground Brick (see "A")

= 240 briquettes,

240 blocks.

LEWIS SOLOMON, *Chairman.*

14.11.07.

D. MORTARS CONTAINING FIVE PER CENT. OF RED LONDON CLAY,
calculated on the dry mortar, the sand being first mixed with the clay

	Tensile Strength.				Crushing Strength.			
	1 Month	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
Lime used—	*Dorking Greystone.*							
With Standard Sand (Leighton Buzzard)								
1 Lime 3 Sand	——	——	——	——	——	——	——	——
,, ,,	——	——	——	——	——	——	——	——
,, ,,	——	——	——	——	——	——	——	——

Repeat above with—
Fine Sand (Charlton)
Pit Sand (Ordinary)

Repeat the whole of the above with
White Chalk Lime
Blue Lias Lime
= 108 briquettes,
108 blocks.

LEWIS SOLOMON, *Chairman.*
14.11.07.

E. BRICK TESTS FOR ADHESION

	Stocks.				Flettons.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
Dorking Greystone Lime.								
1 vol. Lime 3 vols. Standard Sand	——	——	——	——	——	——	——	——
,, ,, ,,	——	——	——	——	——	——	——	——
,, ,, ,,	——	——	——	——	——	——	——	——
1 vol. Lime 3 vols. Fine Sand	——	——	——	——	——	——	——	——
,, ,, ,,	——	——	——	——	——	——	——	——
,, ,, ,,	——	——	——	——	——	——	——	——
1 vol. Lime 3 vols. Pit Sand	——	——	——	——	——	——	——	——
,, ,, ,,	——	——	——	——	——	——	——	——
,, ,, ,,	——	——	——	——	——	——	——	——
1 vol. Lime 3 vols. Thames Sand	——	——	——	——	——	——	——	——
,, ,, ,,	——	——	——	——	——	——	——	——
,, ,, ,,	——	——	——	——	——	——	——	——
1 vol. Lime 3 vols. Ground Brick	——	——	——	——	——	——	——	——
,, ,, ,,	——	——	——	——	——	——	——	——
,, ,, ,,	——	——	——	——	——	——	——	——

= 120 pairs of bricks,

240 bricks required.

Referred to next meeting.

LEWIS SOLOMON, *Chairman.*

14.11.07.

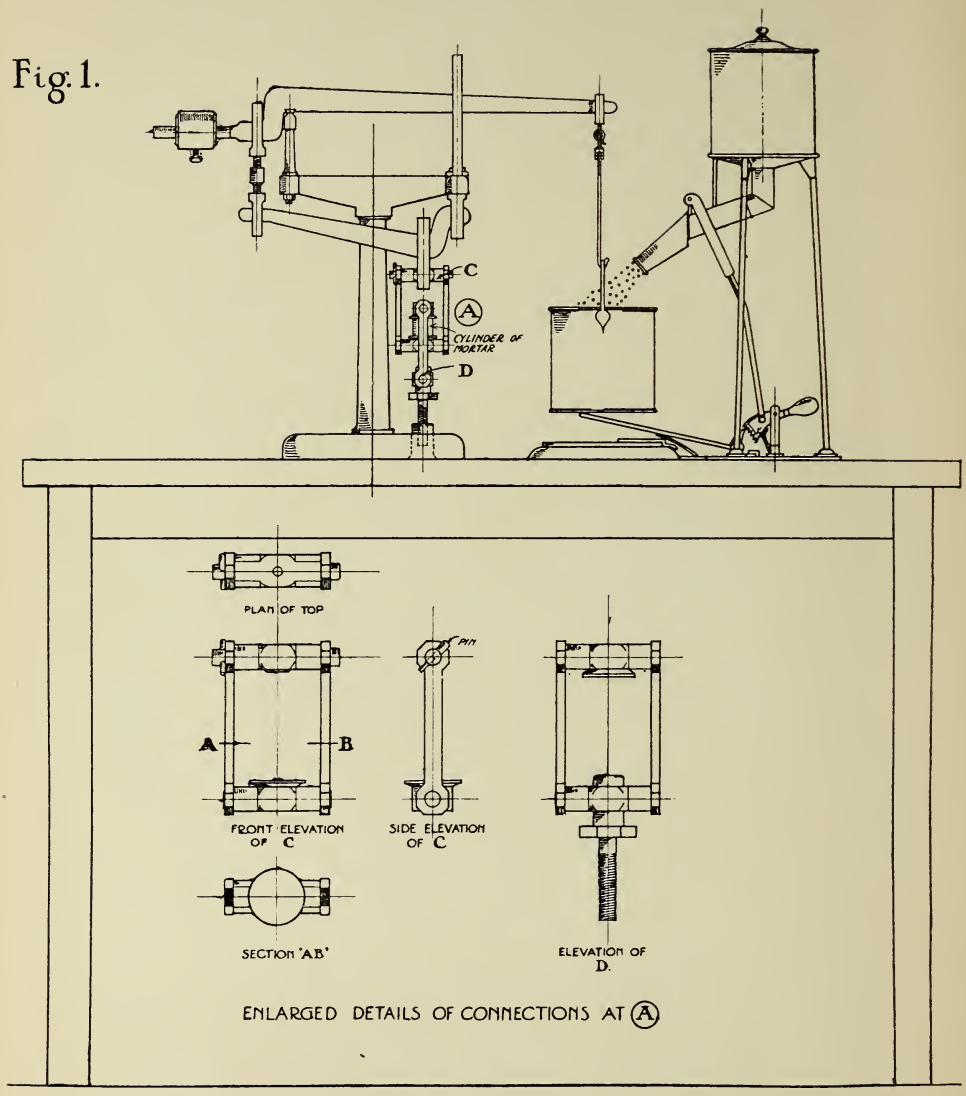
SUMMARY

Series A	240 Briquettes	240 Blocks
„ B	240 „	240 „
„ C	240 „	240 „
„ D	108 „	108 „
Total	828 Briquettes	828 Blocks

Adhesion Tests.

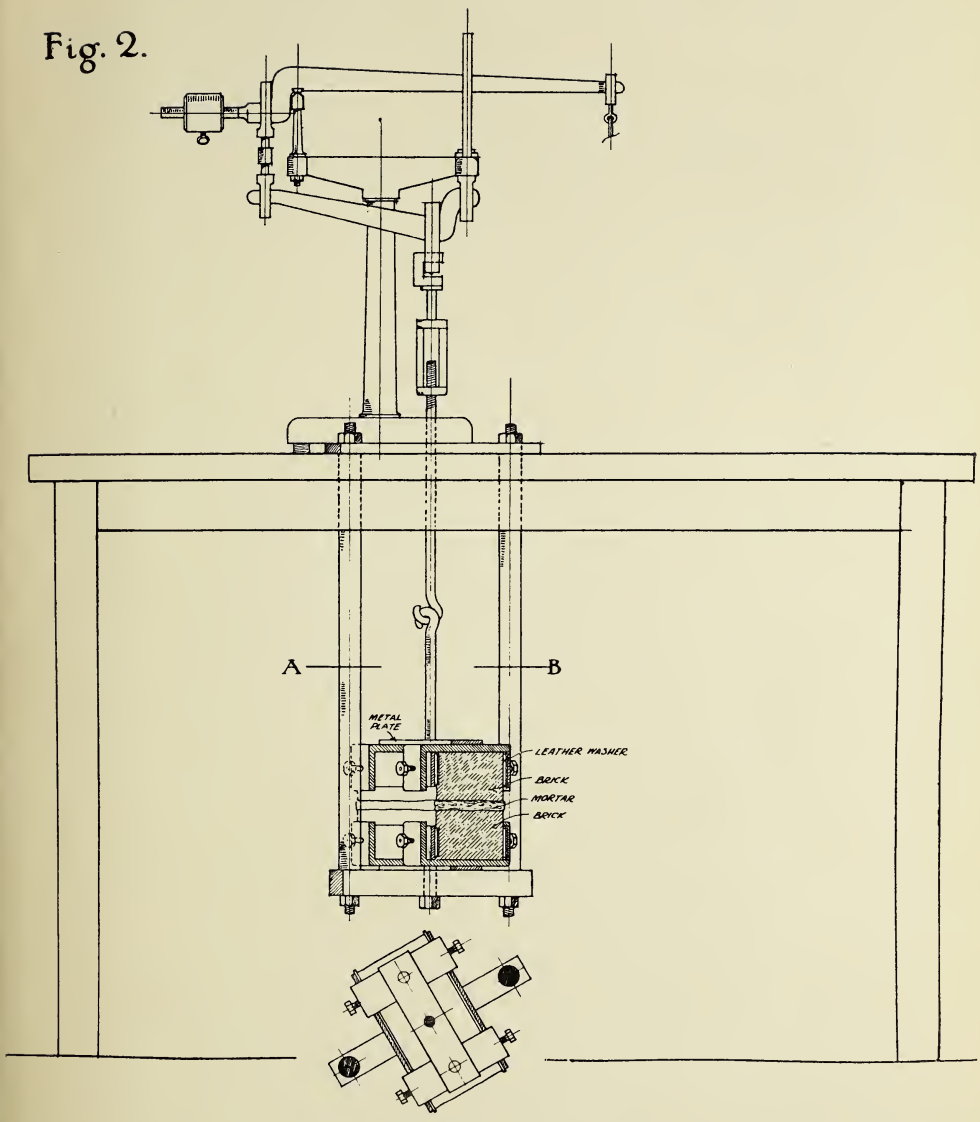
	120 pairs of Bricks.
Total Briquettes . .	828
„ Blocks . . .	828
„ Bricks . . .	120
Grand total .	1776

Fig. 1.



Compound Lever Cement-Testing Machine

Fig. 2.



Compound Lever Cement-Testing Machine

Modification of the Compound Lever Cement Testing Machine for Crushing and Adhesive Tests, Designed by G. E. Moore, Esq., M.Inst.Mech.E., etc., for the purpose of this Investigation.

The usual jaws for holding briquettes having been removed, two circular discs are placed in position, the lower disc being suspended from the lever arm and the upper supported by rods attached to the base of the machine, as shown in the subjoined illustration.

When the block to be crushed is placed between the two discs it takes the full power of the machine as does a briquette, with the difference that the usual jaws pull the briquette asunder, whilst the discs crush the block between them. As each disc is on a swivel joint it automatically adjusts itself to any difference in the planes of the two horizontal surfaces of the block due to contraction in drying, etc.

The modification for the adhesive test is effected by suspending a mild steel rod from the lever arm in place of the usual upper briquette jaw, and carrying this down through the base of the machine and the table to the upper of a pair of claw grips, which hold the bonded bricks in position by means of side bolts pressing on iron plates that grip the sides of the bricks, a piece of leather being placed between the plate and the brick to give a better hold than would be obtained by the metal, thus preventing slip; and at the same time undue pressure on any slight projecting surface by reason of the irregularity of the brick is avoided. To resist the upward pull of the lever the bottom claw or "cradle" is bolted to two steel tubes screwed into an iron plate on which the machine stands, the whole being thus perfectly rigid and free from outside strain during the test. The subjoined illustration will make the method clear.

SECTION II

TABLE I

EXAMINATION OF LIMES USED DURING EXPERIMENTS

Chemical Analyses.	Composition of Dry, Fresh Lime.		
	White Chalk Lime.	Dorking Greystone Lime.	Blue Lias Lime.
Insoluble Residue	Trace %	Trace %	2·83 %
Soluble Silica	0·77	5·79	15·08
Oxide of Iron and Alumina . .	2·21	3·62	11·09
Lime as CaO.	97·00	81·18	66·06
Calcium Carbonate. $CaCo_3$ . .	Trace	7·21	Trace
Calcium Sulphate. $CaSO_4$ . .	Trace	1·06	2·34
Magnesia	Trace	1·14	0·42
Alkalies and Loss (by difference) .	0·02	Trace	2·18
	100·00 %	100·00 %	100·00 %

TABLE II

EXAMINATION OF AGGREGATE USED DURING EXPERIMENTS

Description.	Standard (Leighton Buzzard).	Fine Sand (Charlton)	Pit Sand (Ordinary)	Thames Sand.	Ground Brick.
Grading—					
Retained on $\frac{1}{4}''$ . .	Passed $\frac{1}{20}''$ and retained on $\frac{1}{30}''$	0·0	8·1	0·8	15·8
,, ,, $\frac{1}{8}''$ . .		0·0	14·8	5·2	7·6
,, ,, $\frac{1}{16}''$ . .		0·8	12·4	12·6	8·0
,, ,, $\frac{1}{32}''$ . .		0·8	5·4	11·8	6·4
,, ,, $\frac{1}{50}''$ . .		24·5	28·8	53·2	13·6
,, ,, $\frac{1}{75}''$ . .		13·7	20·3	12·8	11·6
Passed $\frac{1}{75}''$ . .		60·2	10·2	3·6	37·0
		100·0	100·0	100·0	100·0
Passed * $\frac{1}{32}''$ %	0·0	98·4	59·3	69·6	62·2
,, $\frac{1}{50}''$ %	0·0	73·9	30·5	16·4	48·6
,, $\frac{1}{75}''$ %	0·0	60·2	10·2	3·6	37·0

All samples free from clay.

* See Section IV, p. 21.

SECTION III

DIAGRAMMATIC RESULTS

A STUDY of the tabulated results as set out in the diagrams brings into view in a convenient form many points of interest well worth careful examination, a noticeable one being the decrease in strength of certain mortars, particularly those made with white chalk lime, after drying by storage on the shelves of the testing room in the basement of the building, which consequently was at a fairly constant temperature throughout the year. At first the fact that a mortar decreased in strength after three or twelve months seemed to throw some doubt upon the accuracy of the work, but a more careful comparison of the factors in view of the above consideration clearly points to the fact that a well-set mortar under certain conditions loses a percentage of its strength on drying. It will be noticed that this phenomenon applies almost entirely to those of an inferior quality.

SERIES A. WHITE CHALK LIME

TENSILE STRENGTHS

Diagram Aa.—With Standard Sand the best results were obtained with proportions of 1 to 4, the two years' test giving 65 lb. per sq. in., all the tests above one month giving close agreement.

Diagram Ab.—With Charlton Fine Sand the best two years' result, viz. 60 lb., was obtained with ratio of 1 to 4, proportions 1 to 5 falling to 32 lb. In this case the strength of the twelve months' samples was markedly higher, rising to 86 and even to 92 in the case of proportions 1 to 2, and it is only reasonable to assume that as the briquettes dried they lost the "grip" due to moisture.

Diagram Ac.—With Pit Sand proportions 1 to 2 gave distinctly the best results, viz. 73 lb. in two years, the twelve months' test having been as high as 89. There was little practical difference between the other proportions.

Diagram Ad.—With Thames Sand proportions 1 to 2 in two years gave 100, this being only 1 lb. less than the twelve months. As with pit sand, other proportions gave lower and fairly equal results.

Diagram Ae.—With Ground Brick the best results were obtained with proportions 1 to 2 and 1 to 5, viz. in two years, 60 and 52 lb. respectively.

Crushing Strengths

Diagram Aa'.—With Standard Sand the maximum result in two years was obtained with 1 to 3, viz. 240 lb. per cu. in.; proportions 1 to 2 and 1 to 4 gave nearly as good, but 1 to 5 gave only 45 lb. In the case of 1 to 3 the crushing strength increased up to 308 in twelve months and then fell to 240 in the dry mortar, *i. e.* in two years.

Diagram Ab'.—With Charlton Fine Sand proportion 1 to 2 gave a strength of 300 lb. in two years, which steadily fell with increasing aggregate to 88 lb. with proportion 1 to 5.

Diagram Ac'.—With Pit Sand proportions of 1 to 2 gave 247 lb., and 1 to 3, 253 lb. in two years, and then decreased with increased aggregate. In this diagram the effect of drying is noticeable, the twelve months' tests with 1 to 2 having been as high as 385.

Diagram Ad'.—With Thames Sand proportions 1 to 2 gave 297 lb. in two years; again the effect of drying is well shown, twelve months' tests with 1 to 2 having been as high as 406 lb.

Diagram Ae'.—With Ground Brick 312 lb. were obtained in two years with proportions 1 to 3, but this figure steadily fell to 152 with 1 to 5.

SERIES B. DORKING GREYSTONE LIME

Tensile Strengths

Diagram Ba.—With Standard Sand far more consistent results are seen than in Series A in regard to the time factor. With proportions 1 to 3 the two years' test gave the maximum result, viz. 103 lb. per sq. in., a result, however, but little better than that obtained with 1 to 2, viz. 97 lb., proportions 1 to 4 and 1 to 5 fell off to 32 and 27 respectively, and it is of interest to note that with these latter "bad mortars," as they may be termed, the partially dried samples gave better results than the two years' tests.

Diagram Bb.—With Charlton Fine Sand the results were all poor, only 50 lb. being obtained with proportions 1 to 2 in two years.

Diagram Bc.—With Pit Sand 75 lb. were obtained in two years with proportions 1 to 3. Here it is again very noticeable that the time sequence is in order with the best results, but erratic with the lower qualities.

Diagram Bd.—With Thames Sand the best result (again in time sequence) was with proportions 1 to 2, viz. 88 lb. per sq. in. in two years. The effect of the moisture in this diagram is marked, with proportions 1 to 4 it might have been concluded from a three months' test that a strength of 95 lb. was attainable.

Diagram Be.—With Ground Brick the results were all poor and erratic, the maximum result in two years being obtained with proportions 1 to 4, viz. 48 lb., although the moist briquettes tested at twelve months gave 60 lb.

Crushing Strengths

Diagram Ba'.—With Standard Sand 257 lb. per cu. in. were obtained in two years with proportions 1 to 2, the results steadily falling to 48 with 1 to 5, the "false result" due to the moisture in the twelve months' samples being very marked.

Diagram Bb'.—With Charlton Fine Sand only 180 lb. per cu. in. were obtained in two years with proportions 1 to 5.

Diagram Bc'.—With Pit Sand 333 lb. per cu. in. were obtained in two years with proportions 1 to 2, proportions 1 to 3, etc., giving distinctly inferior results.

Diagram Bd'.—With Thames Sand 243 lb. per cu. in. were obtained in two years with proportions 1 to 2. It is very interesting to note the "false result" given by the three months' test with proportions 1 to 3, viz. 430 lb. In this case evidently the effect of the capillarity of the water was acting under the most favourable conditions.

Diagram Be'.—With Ground Brick the best results, viz. 162 lb., were obtained with proportions 1 to 3, the time sequence being in order, but erratic in all other cases.

SERIES C. BLUE LIAS LIME

Tensile Strengths

Diagram Ca.—With Standard Sand proportions 1 to 2 decidedly gave the best results, viz. 58 lb. per sq. in. in two years, falling to only 11 lb. with 1 to 4.

Diagram Cb.—With Charlton Fine Sand, again, proportions 1 to 2 gave the best, viz. 40 lb. in two years, and the results fell off to about one half with proportions 1 to 3, etc.

Diagram Cc.—With Pit Sand a marked improvement was effected, the time sequence being in order and 75 and 77 lb. being obtained with proportions 1 to 2 and 1 to 3 respectively in two years. With increase of aggregate the strength showed a marked diminution and the time sequence varied considerably.

Diagram Cd.—With Thames Sand the proportions 1 to 3 gave 102 lb. per sq. in. in two years, the time sequence being in order. The deleterious effect of alteration of proportions either way is very marked, the strengths being lower and the time sequence erratic.

Diagram Ce.—With Ground Brick the best tensile strengths were obtained, viz. 133 lb. in two years with proportions 1 to 2, the time sequence being perfect. With increased aggregate the results fell to 87 lb., with perfect time sequence, but after that proportions 1 to 4 and 1 to 5 gave variable results, the danger of accepting a one month test with 1 to 5 being distinctly indicated.

Crushing Strengths

Diagram Ca'.—With Standard Sand the two years' test gave 538 lb. per cu. in. with proportions 1 to 2. It is interesting to note that if the well-known proportions of 1 to 3 had been solely tested this mortar would have been dismissed as having a crushing strength of only 188. Here, clearly, the magic 1 to 3 is largely at fault.

In the case of proportions 1 to 2 it will be noticed the time sequence is perfect.

Diagram Cb'.—With Charlton Fine Sand the results were inferior, only 257 lb. being obtained in two years with proportions 1 to 2, and the twelve months' test gave higher results. Increased aggregate only made matters worse.

Diagram Cc'.—With Pit Sand a very different result was at once seen. *All* the proportions gave regular time sequences, and 1 to 2 gave 605 lb., 1 to 3 gave 650 lb., 1 to 4 gave 548 lb., but 1 to 5 gave only 303 lb. per cu. in.

Diagram Cd'.—With Thames Sand the results were still better, viz. 785 lb. in two years for proportions 1 to 2, the time sequence being perfect. Increased aggregate only decreased strength.

Diagram Ce'.—With Ground Brick 910 lb. were obtained with proportions 1 to 2 in two years, the time sequence being excellent. As before, increased aggregate meant decreased strength.

SERIES D. ADDITION of 5 PER CENT. CLAY to AGGREGATE

ALL PROPORTIONS 1 TO 3

Tensile Strength

Diagram Da.—White Chalk Lime with standard sand gave 50 lb. in two years and with pit sand 57 lb., but with Charlton only 35 lb. per sq. in. The twelve months' tests gave much higher results, as might be expected from the retention of moisture by the clay.

Diagram Db.—Dorking Greystone Lime with pit sand gave the best of this set, viz. 67 lb. in two years, the Charlton fine sand giving only 20 lb.

Diagram Dc.—Blue Lias Lime and standard sand gave 168 lb. in two years, and with pit sand 121 lb., whilst the best obtained with Charlton fine sand was only 34.

Crushing Strength

Diagram Da'.—White Chalk Lime and standard sand gave the best results, viz. 230 lb. per cu. in. in two years, and Charlton fine sand gave the lowest, viz. 70 lb.

Diagram Db'.—Dorking Greystone Lime also gave poor results; the best being 177 lb. in two years with standard sand and only 82 with Charlton fine.

Diagram Dc'.—Blue Lias Lime and standard sand gave 876 lb. in two years. With pit sand, 550 lb. were obtained, but only 79 lb. with Charlton fine.

SERIES G. COMPARISON OF RESULTS WITH AND WITHOUT CLAY

WHITE CHALK LIME, 1 TO 3

Tensile Strength

Diagram Ga.—Without Clay the best result in two years was obtained with Charlton fine sand, viz. 55 lb. per sq. in.

With Clay standard sand gave 50 lb. in two years, pit sand 57 lb. Charlton fine sand giving only 35 lb. in two years respectively, the time sequence being variable as in all low results, the twelve months' tests being much higher.

DORKING GREYSTONE LIME

Tensile Strength

Diagram Gb.—Without Clay standard sand gave 103 lb. in two years, pit sand 75 lb., and Charlton fine sand only 35 lb. per sq. in.

With Clay pit sand gave 67 lb., standard sand 48 lb., and Charlton fine only 20 lb. per sq. in. in two years, the twelve months' tests giving higher results in each case.

BLUE LIAS LIME

Tensile Strength

Diagram Gc.—Without Clay pit sand gave 77 lb. in two years, standard sand 38 lb., and Charlton fine only 26 lb. per sq. in.

With Clay standard sand gave 168 lb., pit sand 121 lb., and Charlton fine sand 33 lb. per sq. in.

WHITE CHALK LIME

Crushing Strength

Diagram Ga'.—Without Clay fine Charlton sand gave in two years 260 lb. per per cu. in.

With Clay fine Charlton sand gave only 70 lb. per cu. in., whilst standard sand gave 230 lb. and pit sand 163 lb. per cu. in.

Thus clay with white chalk lime in proportions of 1 to 3 is injurious.

DORKING GREYSTONE LIME

Crushing Strength

Diagram Gb'.—Without Clay gave a maximum in two years of 228 lb. with standard sand, against Charlton fine sand 140 lb., and 200 lb. per cu. in. for pit sand.

With Clay standard sand gave 177 lb. in two years, fine Charlton sand only 82 lb., and pit sand 140 lb. per cu. in.

BLUE LIAS LIME

Diagram Gc'.—Without Clay pit sand gave 650 lb. in two years, the results being in sequence of time, Charlton fine sand only 156 lb., and standard sand 188 lb. per cu. in.

With Clay standard sand gave 876 lb. in two years, Charlton fine sand 79 lb., and pit sand 550 lb.

Brick Tests for Adhesion

STOCK BRICKS

Diagram E. All mortars 1 *to* 3.

DORKING GREYSTONE LIME

Ground Brick gave an adhesive strength of 232 lb. in two years, being nearly double the strength obtained with Thames sand, four times that for pit sand, fine sand and standard sand.

Fletton Bricks

DORKING GREYSTONE LIME 1 to 3.

Ground Brick gave the maximum, viz. 347 lb., the results steadily falling for Thames sand 293, pit sand 200, Charlton fine sand 87, and standard sand 122 lb. The Fletton bricks consistently gave a better bond than stock bricks.

NOTE.—In the course of testing for adhesive strength it was noticed that in those cases where the greatest strength was obtained, the mortar, instead of leaving the brick, broke in itself, portions of mortar adhering to both bricks.

SECTION IV

RELATION OF GRADING OF AGGREGATE AND PRESENCE OF CLAY TO STRENGTH OF MORTAR

THE effect of fine material in the aggregate is brought out very clearly in these experiments, especially in those in which 5 % of clay was added to the aggregate.

Placing the aggregate in the order of increasing percentage of finer particles (see Table II, p. 14), we have—

TABLE III

		Per cent.
Passed $\frac{1}{32}$ in. mesh.		
	Standard sand	0·0
	Pit sand	59·3
	Ground brick	62·2
	Thames sand	69·6
	Charlton fine sand	98·4
Passed $\frac{1}{50}$ in. mesh.		
	Standard sand	0·0
	Thames ,,	16·4
	Pit ,,	30·5
	Ground brick	48·6
	Charlton fine sand	73·9
Passed $\frac{1}{75}$ in. mesh.		
	Standard sand	0·0
	Thames ,,	3·6
	Pit ,,	10·2
	Ground brick	37·0
	Charlton fine sand	60·2

On tabulating the tests made with lime and aggregate in the ratio of 1 to 2 and 1 to 3, for example, we have the following series—

TABLE IV

Proportion of Lime to Sand.	Results of Two Years' Tests.			
	1 to 2.		1 to 3.	
	Tensile.	Crushing.	Tensile.	Crushing.
Without Clay.				
White Chalk and Standard Sand . . .	43	218	53	240
,, ,, Fine Charlton Sand . .	53	300	55	260
,, ,, Pit Sand	73	247	50	253
,, ,, Thames Sand . . .	100	297	68	202
,, ,, Ground Brick . . .	60	213	40	312
Dorking Greystone and Standard Sand . .	97	257	103	228
,, ,, Fine Charlton Sand .	50	143	35	140
,, ,, Pit Sand . . .	62	333	75	200
,, ,, Thames Sand . .	88	243	58	228
,, ,, Ground Brick . .	38	123	27	162
Blue Lias and Standard Sand. . . .	58	538	38	188
,, ,, Fine Charlton Sand . . .	40	257	26	156
,, ,, Pit Sand	75	605	77	650
,, ,, Thames Sand	80	785	102	507
,, ,, Ground Brick	133	910	87	657
With 5% Clay.				
White Chalk and Standard Sand . . .	—	—	50	230
,, ,, Fine Charlton Sand . .	—	—	35	70
,, ,, Pit Sand	—	—	57	163
Dorking Greystone and Standard Sand . .	—	—	48	177
,, ,, Fine Charlton . .	—	—	20	82
,, ,, Pit Sand . . .	—	—	67	140
Blue Lias and Standard Sand. . . .	—	—	168	876
,, ,, Fine Charlton Sand . . .	—	—	34	79
,, ,, Pit Sand	—	—	121	550

From this table it will be seen that—

1. *The Fine Charlton Sand* gave good results with white chalk lime, but with lias lime it made a very indifferent mortar; and when clay was added it gave the lowest results.

2. *Ground Brick*, the next aggregate in order of fineness, gave good results with white chalk lime but inferior with Dorking greystone lime. With blue lias lime, however, it gave the second best results in tensile and the best results in crushing strength. Unfortunately, from the experimental standpoint, the test was not repeated with clay as, obviously, it is hardly likely that ground brick would contain unburnt clay.

3. *Pit Sand*, the third aggregate in order of fineness, gave good results with white chalk lime and Dorking greystone lime; with blue lias lime it gave excellent results, viz. tensile 77, crushing 650. With the addition of clay in the white chalk lime tests, the crushing strength fell off, a similar result being obtained with Dorking greystone lime, the tensile strength in each case

being increased. When blue lias lime, however, was used, the tensile strength was increased from 77 to 121, but the crushing fell off from 650 to 550 lb. per cu. in.

4. *Thames Sand.*—As might be expected, the tests with this sand, although showing certain variations, on the whole ran fairly well with those made with pit sand, especially if we have regard to the experimental error unavoidable in work of this nature.

5. *Standard Sand.*—This, the coarsest of the aggregates, showed fair average results with white chalk lime, and twice the tensile strength with Dorking greystone lime. With blue lias lime the results were decidedly poor with proportions of 1 to 3, thus showing that evidently the voids were not completely filled. With 1 to 2 far better results were obtained. Where a small quantity of clay was added to the sand the results were excellent, viz. 168 for tensile strength and 876 for crushing, against 38 and 188 respectively for the 1 to 2 tests, indicating that with such a coarse sand the addition of clay was distinctly advantageous as against its decidedly deteriorating effect when such a fine sand as that from Charlton was employed.

Perhaps this point is one of the most interesting and valuable which has been brought out in the investigation.

SECTION V

MAXIMUM RESULTS SHOWING VARIATIONS IN COMPOSITION OF MORTAR WHICH MAY BE EMPLOYED WITH DIFFERENT QUALITIES OF MATRIX (LIME) AND AGGREGATE (SAND)

Results of Tests at End of Two Years

A.

TABLE V

WHITE CHALK LIME with—		*Tensile.*	*Crushing.*
Standard Sand	1 : 3	53 lb.	240 lb.
	1 : 4	65 „	223 „
Average	1 : 3½	59 lb.	231 lb.
Fine Sand (Charlton)	1 : 2	53 lb.	300 lb.
(*Note.*—1 : 4 gave higher tensile, viz. 60, but lower crushing, viz. 217.)			
Pit Sand (ordinary)	1 : 2	73 lb.	247 lb.
	1 : 3	50 „	253 „
Average	1 : 2½	61 lb.	250 lb.
Thames Sand	1 : 2	100 lb.	297 lb.
Ground Brick	1 : 2	60 „	213 „
	1 : 3	40 „	312 „
	1 : 4	38 „	222 „
Average	1 : 3	46 lb.	249 lb.

B.

DORKING GREYSTONE LIME with—		*Tensile.*	*Crushing.*
Standard Sand	1 : 2	97 lb.	257 lb.
	1 : 3	103 „	228 „
Average	1 : 2½	100 lb.	242 lb.
Fine Sand (Charlton)	1 : 2	50 lb.	143 lb.
	1 : 5	27 „	180 „

(*Note.*—In this case the tensile and crushing strengths reversed, 1 : 2 giving the highest tensile and 1 : 5 the highest crushing strength.)

Pit Sand (ordinary)	1 : 2	62 lb.	333 lb.
	1 : 3	75 „	200 „
Average	1 : 2½	68 lb.	266 lb.
Thames Sand	1 : 2	88 lb.	243 lb.

(*Note.*—The crushing strength 1 : 3 was 430 lb. in three months, 323 lb. in twelve months, but only 228 lb. in two years, thus showing an apparent remarkable deterioration due to drying.)

Ground Brick	1 : 2	38 lb.	123 lb.
	1 : 3	27 „	162 „
	1 : 4	48 „	130 „
	1 : 5	38 „	142 „
Average	1 : 3½	35 lb.	139 lb.

C.

BLUE LIAS LIME with—		*Tensile.*	*Crushing.*
Standard Sand	1 : 2	58 lb.	538 lb.
Fine Sand (Charlton)	1 : 2	40 „	257 „
Pit Sand (ordinary)	1 : 3	77 „	650 „
Thames Sand	1 : 2	80 „	785 „
	1 : 3	102 „	507 „
Average	1 : 2½	91 lb.	646 lb.
Ground Brick	1 : 2	133 lb.	910 lb.

D.

		Tensile.	*Crushing.*
WHITE CHALK LIME + 5 % *Red London Clay* with—			
Standard Sand	1 : 3	50 lb.	230 lb.
DORKING GREYSTONE LIME + 5 % *Red London Clay* with—			
Standard Sand	1 : 3	48 lb.	177 „
Pit Sand	1 : 3	67 „	140 „
BLUE LIAS LIME + 5 % *Red London Clay* with—			
Standard Sand	1 : 3	168 „	876 „

This table is of special interest as indicating at a glance the proportions of matrix and aggregate which should be used with any given materials of those experimented with, to yield the maximum results. For instance, if a Dorking greystone lime is employed, it will be seen that ordinary pit sand in the ratio of 1 to 2 will yield the highest crushing strength, viz. 333 lb. per cu. in., but if a blue lias lime is employed, ground brick, in the ratio of 1 to 2, will yield a crushing strength of no less than 910 lb. per cu. in., with a tensile strength of 133 lb. per sq. in.; but if a higher tensile strength is required, standard sand with 5 per cent. clay will give 168 lb. per sq. in. with a crushing strength of 876 lb. per cu. in.

SECTION VI

RATIOS OF TENSILE TO CRUSHING STRENGTHS

TABLE VI

$$\frac{\text{Crushing}}{\text{Tensile}} = x$$

Ratios of tests which gave maximum tensile strength thus, *3·0*.
,, ,, ,, ,, crushing strength thus, **7·8**.
,, ,, ,, ,, in both tensile and crushing strengths thus, **6·8**.

		Average of Two Years' Tests. $x =$				
		Standard Sand.	Charlton Sand.	Pit Sand.	Thames Sand.	Ground Brick.
White Chalk Lime	1 : 2 .	5·1	3·8	3·2	*3·0*	3·5
,, ,,	1 : 3 .	4·5	4·7	5·1	2·9	**7·8**
,, ,,	1 : 4 .	3·4	3·1	3·2	4·0	5·8
,, ,,	1 : 5 .	1·7	2·8	3·5	3·9	2·9
Dorking Greystone Lime	1 : 2 .	2·6	2·9	**5·4**	2·8	3·2
,, ,, ,,	1 : 3 .	*2·2*	4·0	2·7	3·9	6·0
,, ,, ,,	1 : 4 .	2·9	4·1	3·0	2·3	2·7
,, ,, ,,	1 : 5 .	1·8	6·7	3·7	3·7	3·7
Blue Lias Lime	1 : 2 .	9·3	6·4	8·1	10·2	**6·8**
,, ,,	1 : 3 .	4·9	7·1	8·5	5·0	7·6
,, ,,	1 : 4 -	13·6	6·7	9·1	5·7	6·0
,, ,,	1 : 5 .	10·4	5·8	7·2	6·1	6·6
With 5% Clay.						
White Chalk Lime	1 : 3 .	**4·6**	2·0	3·4	—	—
Dorking Greystone Lime	1 : 3 .	**3·7**	4·1	*2·1*	—	—
Blue Lias Lime	1 : 3 .	**5·2**	2·3	4·5	—	—

On abstracting those ratios which correspond to maximum results as shown in the tables we have the following:—

TABLE VII

		Ratio x =
MAXIMUM TENSILE STRENGTHS		
White Chalk Lime to Thames Sand . .	1 : 2	3·0
Dorking Greystone Lime to Standard Sand .	1 : 3	2·2
Blue Lias Lime to Ground Brick . . .	1 : 2	6·8
With 5% Clay in aggregate.		
White Chalk Lime to Standard Sand . . .	1 : 3	4·6
Dorking Greystone Lime to Pit Sand . . .	1 : 3	2·1
Blue Lias Lime to Standard Sand . . .	1 : 3	5·2
CRUSHING STRENGTH.		
White Chalk Lime to Ground Brick . . .	1 : 3	7·8
Dorking Greystone Lime to Pit Sand . . .	1 : 2	5·4
Blue Lias Lime to Ground Brick . . .	1 : 2	6·8
With 5% Clay in Aggregate.		
White Chalk Lime to Standard Sand . . .	1 : 3	4·6
Dorking Greystone Lime to Standard Sand. .	1 : 3	3·7
Blue Lias Lime to Standard Sand . . .	1 : 3	5·2

SECTION VII

THE EXAMINATION OF ANCIENT MORTARS

In accordance with a suggestion made at a meeting of the Royal Institute of British Architects, some of the members have been good enough to collect a series of authenticated old mortars and to forward these for the purpose of analysis and physical examination.

The results of these examinations are set out in the attached table (VIII.). The samples are twenty-nine in number and form a good representative set.

The essential features brought out by the specially designed system of tests applied, in which particular attention has been paid to aggregate, may shortly be summarised as follows:—

1. That there is no evidence of the formation of soluble silica, the percentage of soluble silica in the best mortars being quite normal for modern mortars made from similar materials. Where larger quantities have been found, the character of the mortar leads to the belief that trass or pozzuolana, etc., had been employed.

2. That the presence of small quantities of clean ferruginous clay in the aggregate has certainly had no deleterious effect on the mortar, as such samples were amongst the best.

3. That the proportion of lime to sand and grit is usually much greater than 1 to 3. For instance, in the samples from Allington Castle, early thirteenth century, the relative volumes in three samples were 1 to 1·7, 1 to 1·1 and 1 to 1·9, the observations of Mr. W. D. Caroë, who kindly forwarded them, being respectively, "Very good indeed"—"Not so good as 'A,' but fair," and "In fair condition."

In reference to Point 2 it may be remarked that the percentage of clean ferruginous clay in the sand in the above instances was respectively 8·6 per cent., 3·66 per cent. and 4·0 per cent.

Mr. Caroë reported that the A sample is one of the best mediæval mortars he had ever come across, second only to the thirteenth-century mortar at Corfe Castle which successfully resisted the gunpowder of the Cromwellian period.

4. Inferior mortars are at once detected by the examination. For instance, the sample from Painters' Hall, built under Sir Christopher Wren after the Fire of London, contained 15·4 per cent. of earthy matter in the aggregate, which was largely composed of broken red brick, organic débris, carbon, etc., the proportion of lime to aggregate being 1 to 0·53. Under the circumstances it is surprising that a crushing strength of 110 lb. per cu. in. was obtained.

Another remarkable sample of bad 500-years-old mortar is one from the Guild Hall, Norwich, which contained coke and coal, the proportions of lime to aggregate being 3 to 1. It is not surprising that the city engineer reported that "the condition of the mortar was very bad, having slight adhesive powers, and much of the wall was in such weak condition as to enable it to be pulled down by the fingers without the use of tools."

It may be noted that, whenever possible, samples of mortar should be collected in such a manner as to enable pieces of 1 cu. in. to be selected or cut out from larger pieces for the crushing test, which cannot be applied to the broken small stuff.

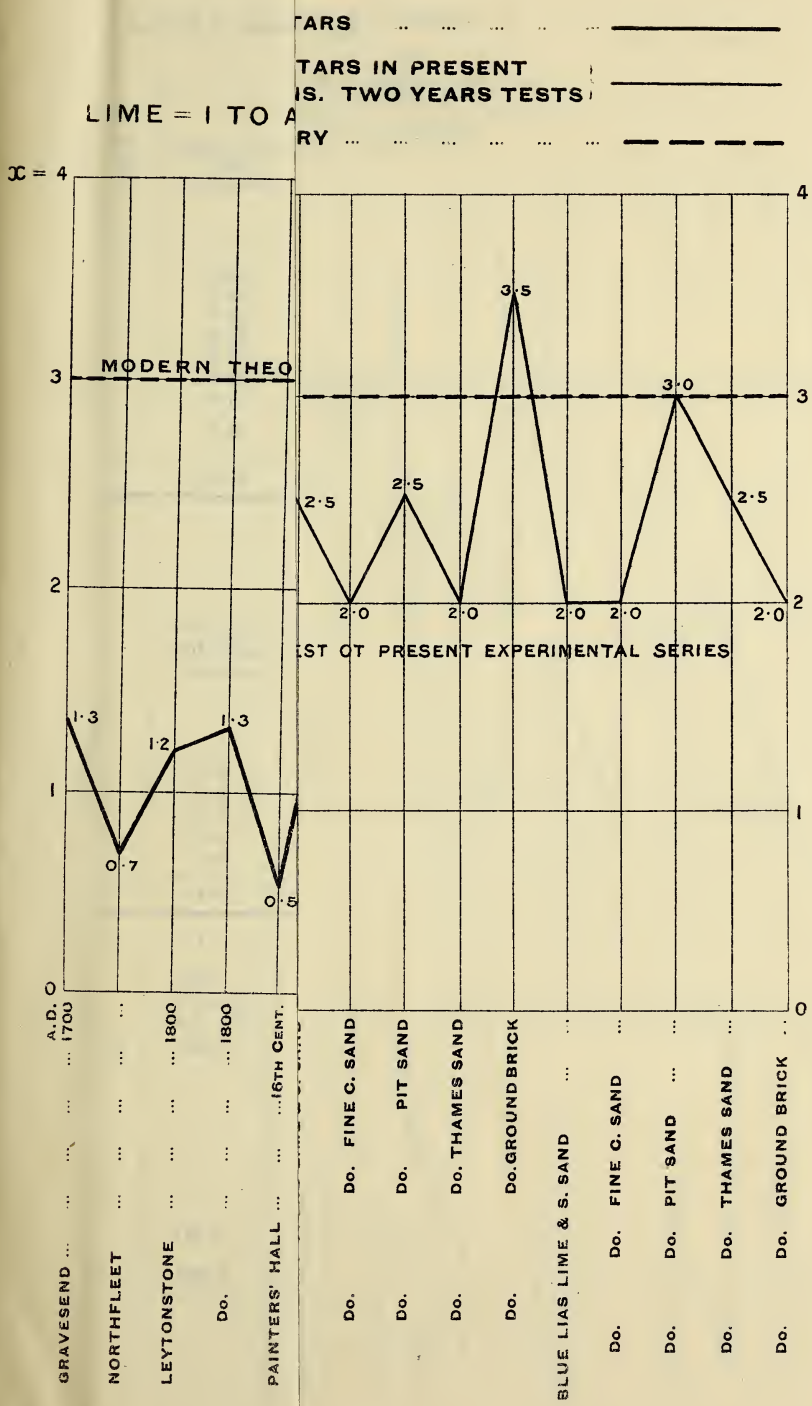
SECTION VIII

COMPARISON OF PROPORTIONS OF LIME TO AGGREGATE IN ANCIENT MORTARS AND THOSE WHICH HAVE GIVEN THE BEST RESULTS IN THE PRESENT INVESTIGATION

DIAGRAM illustrating Table VIII shows very clearly the relative proportions of lime to aggregate in various old mortars, some of them being of the highest quality, in comparison with the aggregate in those mortars which, under the two years' test, have given the best results in the course of the present investigation. From this it will be seen that the greater number of the old samples varied between one and two volumes of aggregate for one of lime, it being remembered always that the calculation is made on the assumption that greystone lime of 80 % of CaO and weighing 40 lb. to the cu. ft. was employed.

The aggregate in the experimental mortars which gave the best results in two years is seen to vary from 2 to 3, the average of the whole being (excluding ground brick tests) 2·27.

From these facts it seems that there is good reason for reconsideration of the modern theoretical hard and fast requirement of proportions of 1 to 3 irrespective of the nature of the lime and aggregate.


TARS
TARS IN PRESENT
IS. TWO YEARS TESTS
RY
LIME = 1 TO A
x = 4
MODERN THEO
ST OF PRESENT EXPERIMENTAL SERIES
1·3
0·7
1·2
1·3
0·5
2·5
2·0
2·5
2·0
3·5
2·0
2·0
3·0
2·0
2·5
GRAVESEND ... ... A.D. 1700
NORTHFLEET ... ...
LEYTONSTONE 1800
Do. 1800
PAINTERS' HALL ... ... 16TH CENT.
Do. FINE C. SAND
Do. PIT SAND
Do. THAMES SAND
Do. GROUND BRICK
BLUE LIAS LIME & S. SAND ...
Do. FINE C. SAND
Do. PIT SAND
Do. THAMES SAND
Do. GROUND BRICK

Another remarkable sample of bad 500-years-old mortar is one from the Guild Hall, Norwich, which contained coke and coal, the proportions of lime to aggregate being 3 to 1. It is not surprising that the city engineer reported that "the condition of the mortar was very bad, having slight adhesive powers, and much of the wall was in such weak condition as to enable it to be pulled down by the fingers without the use of tools."

It may be noted that, whenever possible, samples of mortar should be collected in such a manner as to enable pieces of 1 cu. in. to be selected or cut out from larger pieces for the crushing test, which cannot be applied to the broken small stuff.

SECTION VIII

COMPARISON OF PROPORTIONS OF LIME TO AGGREGATE IN ANCIENT MORTARS AND THOSE WHICH HAVE GIVEN THE BEST RESULTS IN THE PRESENT INVESTIGATION

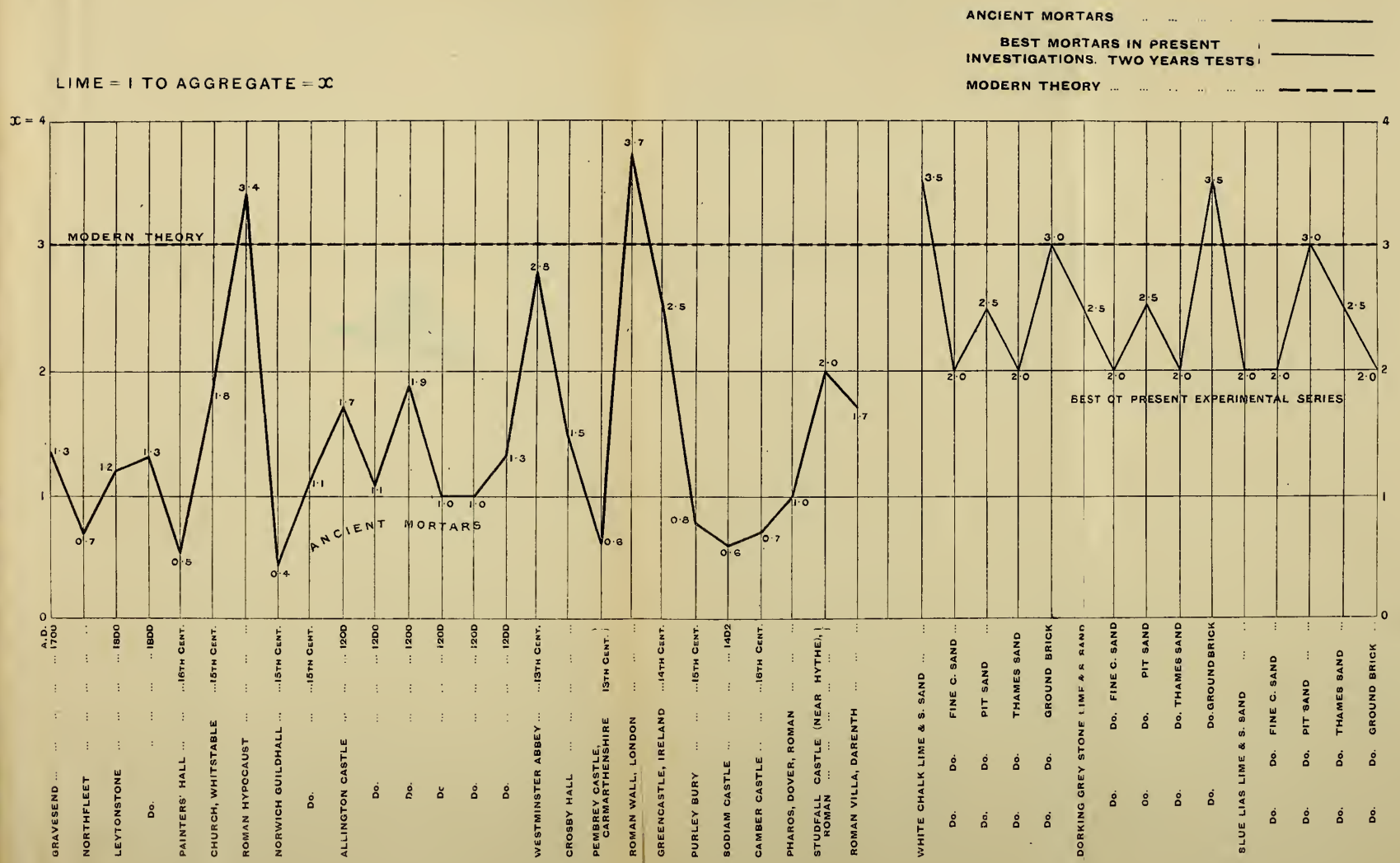
DIAGRAM illustrating Table VIII shows very clearly the relative proportions of lime to aggregate in various old mortars, some of them being of the highest quality, in comparison with the aggregate in those mortars which, under the two years' test, have given the best results in the course of the present investigation. From this it will be seen that the greater number of the old samples varied between one and two volumes of aggregate for one of lime, it being remembered always that the calculation is made on the assumption that greystone lime of 80 % of CaO and weighing 40 lb. to the cu. ft. was employed.

The aggregate in the experimental mortars which gave the best results in two years is seen to vary from 2 to 3, the average of the whole being (excluding ground brick tests) 2·27.

From these facts it seems that there is good reason for reconsideration of the modern theoretical hard and fast requirement of proportions of 1 to 3 irrespective of the nature of the lime and aggregate.

TABLE VIII.

DIAGRAM SHOWING THE PROPORTION OF AGGREGATE IN VARIOUS MORTARS



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ted by H. D. Searles-Wood, Esq.			T. H. Powell, Esq.		
ie, St., h,	Bodiam Castle, ? 1402. (B. Dicksee.)	Camber Castle, Henry VIII, 16th century, per Bernard Dicksee.	Pharos, Dover. Roman.	Studfall Castle. Roman. Nr. Hythe.	Roman villa, Darenth.
	52·04	52·02	44·10	70·20	55·10
	0·45	2·45	0·30	0·30	0·90
	1·64	3·60	2·70	1·40	2·10
	26·10	23·16	27·10	11·30	19·10
	0·38	0·62	5·30	0·20	2·90
	16·60	13·02	7·80	9·20	15·90
	0·19	0·38	0·00	0·00	0·00
	2·32	4·50	12·70	7·40	4·00
	99·72	99·75	100·00	100·00	100·00
	—	—	—	—	—
	—	—	—	—	—
	Fine sand and coarse pebbles	—	Brick	Flint and pebbles	Brick
	—	—	—	—	—
	30·0	—	—	—	—
	5·0	—	—	—	—
	3·0	—	—	—	—
	14·0	—	—	—	—
	2·2	—	—	—	—
	54·2	—	—	—	—
	4·5	5·7	—	—	—
	32·5	29·0	33·9	14·1	23·9
	81·2 : 52·0 = 1 : 0·6	72 : 52·0 = 1 : 0·7	44·9 : 44·1 = 1 : 1·0	35·2 : 70·2 = 1 : 2·0	31·7 : 55·1 = 1 : 1·7
d	Hard	Very hard	—	—	—
	—	—	—	—	—
	—	—	—	—	—
	115 lb.	+ 700 lb.	—	—	—
	100 lb.	—	53·0 lb.	100 lb.	53 lb.

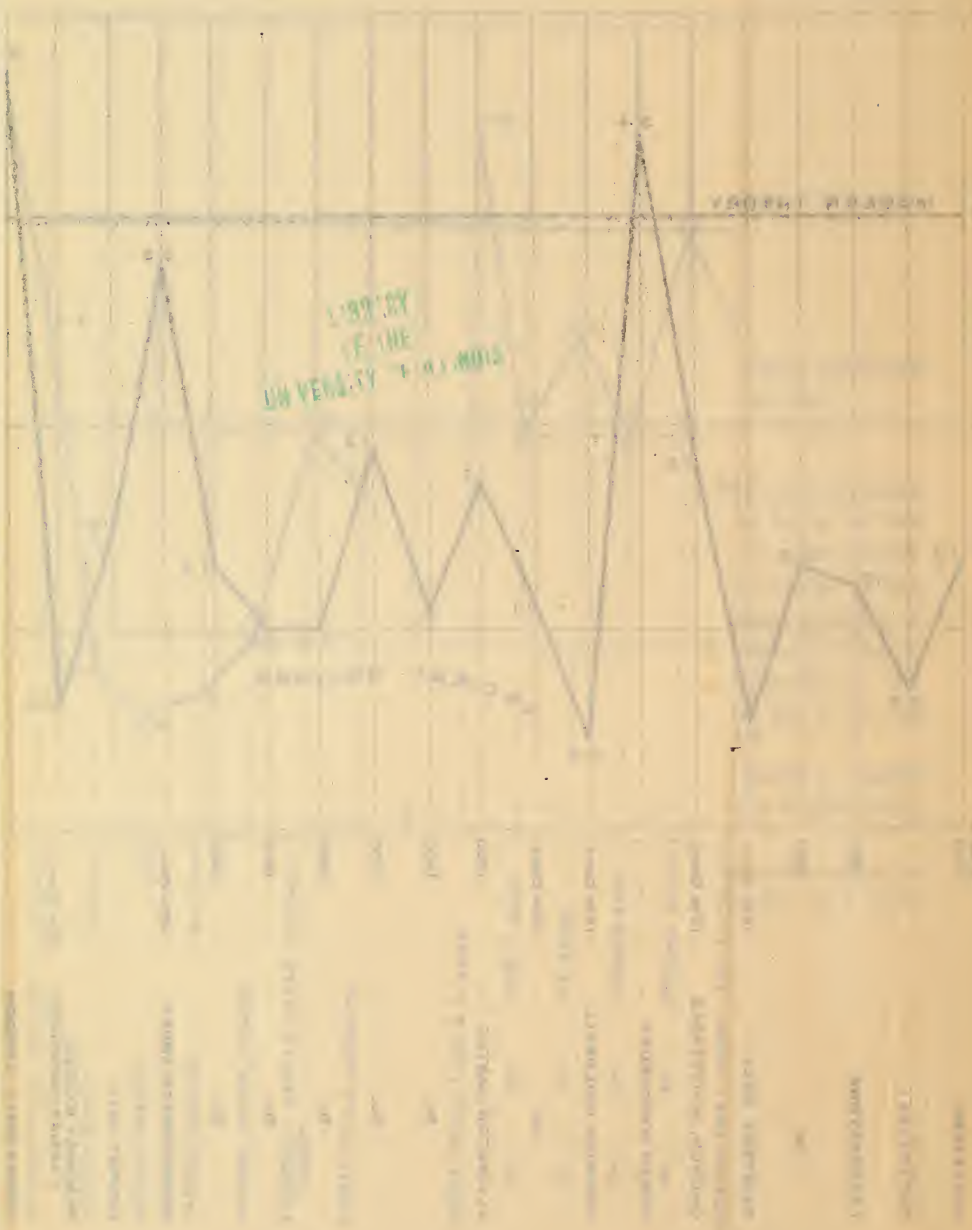

TABLE VIII.—THE COMPOSITION OF ANCIENT MORTARS

DESCRIPTION	Collected by H. D. Searles-Wood, Esq., F.R.I.B.A., etc.									Collected by W. D. Caroë, Esq., F.S.A., etc.										Collected by Lewis Solomon, Esq., F.R.I.B.A., etc.	Collected by W. J. Dibdin, Sydney Perks, City Surveyor, & Max Clarke, F.R.I.B.A.	Collected by Max Clarke, Esq.		Collected by W. J. Dibdin.	Collected by H. D. Searles-Wood, Esq.			T. H. Powell, Esq.		
										Allington Castle.																				
										Early 13th Century.		*12th Century.*																		
	Mantle Pit Wall, *Gravesend*, about 1700.	First Floor Dove R.H., *Northfleet*.	Park House, *Leytonstone*, about 1800.	Park House, *Leytonstone*, Internal Basement Wall, about 1800.	*Painters' Hall* Wall, Trinity Lane, built after the fire of London under Sir Christopher Wren.	Footings of *Church at Whitstable*, Kent, perpendicular, ? late 15th century.	*Roman Hypocaust*, under 39 Bridge St., Chester, by courtesy of A. E. Schofield, Esq.	*Perished Mortar, Norwich Guildhall.* ? 1400.	*Sound Mortar, Norwich Guildhall.* ? 1400.	"A" West Wing, very good indeed.	"B" from N.E. Corner, not so good as "A" but fair.	"C" from Garden Wall, in fair condition.	Wall.	Entrance.	Doorway.	*Westminster Abbey.* Clerestory. ? 13th century.	*Crosby Hall.* Core of the old walls.	*Pembroke Castle, Carmarthenshire.* 13th century.	*Pompeii.* Plaster.	*Roman Wall, London*, from under 2 and 3 Centre Avenue, Leadenhall Market.	*Greencastle, County Down, Ireland.* Wall.	*Greencastle, County Down, Ireland.* Limestone from Interior Angles.	"*Purley Bury*" *Surrey.* Garden Wall foundations ? 15th century.	Old house, Borcsford St., Walworth, ? 1800.	Bodiam Castle, ? 1402. (B. Dickscc.)	Camber Castle, Henry VIII., 16th century, per Bernard Dickscc.	Pharos, Dover. Roman.	Studfall Castle. Roman. Nr. Hythe.	Roman villa, Darenth.
Insoluble in dilute HCl	61·50	52·15	60·12	62·50	38·95	71·50	61·50	27·12	59·55	65·77	60·80	63·22	60·00	56·78	59·82	77·50	58·00	46·26	2·0	73·58	70·66	Trace	40·23	51·08	52·04	52·02	44·10	70·20	55·10
Soluble Silica	0·60	0·50	0·37	0·70	0·05	0·30	2·02	0·70	0·90	1·20	0·70	1·00	0·42	0·84	0·63	1·20	3·80	2·95	0·2	0·30	2·64	Trace	4·00	1·14	0·45	2·45	0·30	0·30	0·90
Oxide of Iron and Alumina	1·10	1·65	0·77	0·65	1·95	2·70	5·30	1·23	3·20	2·40	0·80	4·20	0·62	1·14	1·70	2·20	2·30	1·00	Traces	0·60	2·96	2·10	2·00	5·60	1·64	3·60	2·70	1·40	2·10
Lime (CaO)	16·40	25·00	16·57	16·18	29·72	12·70	9·66	33·84	17·95	13·20	19·10	12·40	19·38	13·76	14·04	8·70	12·50	23·04	54·4	6·40	9·06	54·70	20·40	18·30	26·10	23·16	27·10	11·30	19·10
Magnesia	Trace	Trace	Trace	Trace	Trace	None	Trace	0·33	0·90	Trace	Trace	Trace	Trace	Nil	Nil	0·39	0·36	0·34	Slight trace	Trace	0·82	Trace	Trace	0·46	0·38	0·62	5·30	0·20	2·00
Carbonic Acid (CO_2)	12·70	19·00	13·00	12·60	22·50	10·00	5·00	22·20	10·00	10·20	15·00	9·70	14·40	12·60	7·00	6·55	5·30	5·22	42·3	5·00	3·80	42·98	15·80	14·70	16·60	13·02	7·80	9·20	15·90
Sulphuric Acid (SO_3)	0·34	0·93	Trace	0·20	1·47	Trace	0·60	0·73	Trace	0·31	Trace	Trace	0·60	0·33	0·45	0·00	0·00	0·24	Nil	0·00	0·92	Nil	0·51	0·41	0·19	0·38	0·00	0·00	0·00
Organic Matter and Water of Hydration	0·86	0·60	2·92	1·57	2·91	1·60	15·92	13·04	7·45	1·77	1·30	0·43	4·55	10·00	16·04	2·90	17·50	9·55	1·0	1·23	9·13	0·35	8·01	7·82	2·32	4·50	12·70	7·40	4·00
Moisture	6·50	0·17	6·25	5·60	1·80					5·15	2·30	4·00						10·50	0·0	12·57			9·05						
	100·00	100·00	100·00	100·00	100·25	98·80	100·00	99·24	99·05	100·00	100·00	100·00	99·97	100·45	99·73	94·44	100·26	100·00	99·9	99·68	99·99	100·13	100·00	99·51	99·72	99·75	100·00	100·00	100·00
Earthy Matter per cent.	5·1	1·9	4·9	3·4	5·51	—	1·91	1·16	Trace	5·6	2·17	2·81	2·70	11·07	3·41	4·10	3·20	0·03	The microscopical examination of the organic matter showed this to consist of débris with some fungoid mycelium and vegetable spores	3·62	0·86	—	4·80	—	—	—	—	—	—
Description of Earthy Matter ,,	Brown, earthy, dirty	Reddish brown, earthy, fairly clean	Clean ochre clay	Clean ochre clay	Black and full of organic debris	—	Clay	Clay	—	Red clay, clean	Red clay, clean	Red clay, clean	Clean clay, red	Clean clay, red	Clean clay, red	Clay	Clay	Clean clay		Clean ferruginous sand	Clay	—	Clean clay	—	—	—	—	—	—
Nature of Sand Grit	Grey sand with fibres of organic matter ? road sweepings	Fairly clean gravelly sand	Red gravelly sand	Red gravelly sand	Broken red brick and organic débris, ? old rubbish from ruins of fire	—	Brick with some flint	Flint, with clinker, coke and coal	Fine clean red sand	Clean sand	Clean sand	Clean sand	Fine brick-red	Fine dark-red	Coarse, pebbly, with fine sand	Clean white sand with coarse pebbles	Fine white sand with few pebbles	Very fine and clean		Clean ferruginous sand	Clean grey flint, coarse pebbles	—	Gravel and brick ? chalk	—	Fine sand and coarse pebbles	—	Brick	Flint and pebbles	Brick
Grading of Washed Sand, etc.																													
Retained on ¼ inch Mesh per cent.	Nil	Nil	4·0	4·0	2·57	9·65	0·0	4·5	4·5	13·5	14·5	7·8	0·0	0·0	0·0	45·5	2·5	0·0	—	19·9	21·0	—	8·76	—	—	—	—	—	—
,, ⅛ ,, ,,	2·0	Nil	4·0	6·0	2·76	2·47	12·3	1·6	0·5	5·0	4·5	9·8	0·0	0·0	14·1	2·6	0·8	0·0	—	4·4	8·4	—	1·84	—	30·0	—	—	—	—
,, 1/16 ,, ,,	4·0	6·0	8·0	8·0	2·26	5·24	6·1	1·2	0·5	5·0	3·5	11·0	0·3	1·1	10·7	2·6	0·8	0·0	—	5·3	7·6	—	4·06	—	5·0	—	—	—	—
,, 3/32 ,, ,,	20·0	12·0	8·0	12·0	2·45	4·89	4·6	2·0	2·4	6·5	5·0	11·3	4·5	2·6	8·4	1·9	0·5	0·0	—	7·4	4·2	—	3·35	—	3·0	—	—	—	—
Passed 3/32 ,, ,,	38·0	40·0	36·0	36·0	20·26	47·11	37·4	17·6	51·5	29·5	26·5	28·0	52·5	42·0	23·2	19·9	50·0	45·43	—	35·4	28·7	—	17·42	—	14·0	—	—	—	—
Clay, etc.	5·1	1·9	4·9	3·4	5·51	—	1·9	0·3	—	5·6	2·2	2·8	2·7	11·1	3·4	4·6	3·3	0·93	—	2·5	1·2	—	4·80	—	2·2	—	—	—	—
	69·1	59·9	64·0	69·4	35·81	69·36	62·3	27·2	59·4	65·1	59·2	70·7	60·0	56·8	59·8	77·1	57·9	46·36	—	75·4	71·1		40·23	—	54·2	—	—	—	—
Percentage of Clay, etc. in Grit	7·4	3·2	7·5	4·0	15·4	None	3·1	4·4	Trace	8·6	3·66	4·0	4·5	19·5	5·7	6·0	5·5	2·0	—	3·3	1·2	—	12·0	—	4·5	5·7	—	—	—
Lime corrected to Commercial Lime of 80% CaO per cent.	20·5	31·25	20·71	20·22	37·15	15·9	12·1	42·3	22·44	16·5	23·9	15·5	24·2	23·46	17·55	10·0	15·6	20·03	—	8·0	11·33	—	25·5	—	32·5	29·0	33·9	14·1	23·9
Volume of *Unslaked Lime* to Sand and Grit	*47·8 : 61·5 = 1 : 1·3	*72·8 : 52·1 = 1 : 0·7	*48·3 : 60·1 = 1 : 1·2	*47·2 : 62·5 = 1 : 1·3	71·1 : 38·95 = 1 : 0·5	39·7 : 71·5 = 1 : 1·3	13·1 : 61·5 = 1 : 3·4	74·1 : 27·1 = 1 : 0·4	56·1 : 50·5 = 1 : 1·1	38·4 : 65·8 = 1 : 1·7	55·6 : 60·6 = 1 : 1·1	36·2 : 68·2 = 1 : 1·0	60·6 : 60 = 1 : 1·0	58·6 : 56·7 = 1 : 1·0	43·0 : 59·8 = 1 : 1·3	27·2 : 77·5 = 1 : 2·8	39·0 : 58·0 = 1 : 1·5	69·8 : 46·2 = 1 : 0·6	—	19·7 : 73·6 = 1 : 3·7	28·3 : 70·6 = 1 : 2·5	—	49·2 : 46·2 = 1 : 0·8	—	81·2 : 52·0 = 1 : 0·6	72 : 52·0 = 1 : 0·7	44·9 : 44·1 = 1 : 1·0	35·2 : 70·2 = 1 : 2·0	31·7 : 55·1 = 1 : 1·7
Physical Character of Mortar	Grey, friable	Light, friable	White, very hard	White, hard	Unequally mixed, lumps of lime, some soft, and some hard	None	—	Fairly hard, but crumbling	Hard, good	Very hard	Very hard	Not so hard as "A"	Very hard	Fairly hard	Very hard	Fairly hard	Hard	Very hard	—	Hard concrete character	Fairly hard	Weathered limestone	Very hard	Fairly hard grey	Hard	Very hard	—	—	—
Reaction	Slightly alkaline	Slightly alkaline	Slightly alkaline	Slightly alkaline	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Strongly alkaline	Neutral	Neutral	Neutral	—	Neutral	—	—	—	—	—	—
Free Lime	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	Considerable quantity	None	None	None	—	None	—	—	—	—	—	—
Crushing Strength per cubic inch	Too small to test	Too small to test	125 lb.	Too small to test	110 lb.	Too small to test	13·5 lb.	Too small to test ? 70 lb.	Too small to test ? 100 lb.	144 lb.	90 lb.	Too small to test	162 lb.	97 lb.	194 lb.	Too small to test	Too small to test	650 lb.	—	164 lb.	Too small to test	—	over 500 lb.	66 lb.	115 lb.	+ 700 lb.	—	—	—
Weight of 1 cubic ft. of Grit	—	—	—	—	76·6 lb.	—	60 lb.			94 lb.	94 lb.	94 lb.	100 lb.	100 lb.	100 lb.	100 lb.	100 lb.	100 lb.	—	98·4 lb.	100 lb.	—	77·2 lb.	—	100 lb.	—	53·0 lb.	100 lb.	53 lb.

* Factor used to convert *weight* of commercial lime to volume = 2½.

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SECTION IX

BRICK TESTS FOR ADHESION

Series E F was conducted with the view of ascertaining the adhesive power of certain mortars to two qualities of bricks, viz. Stock and Fletton.

The mortars used were made with Dorking greystone lime in all cases, the aggregates used being, respectively, standard sand, fine Charlton sand, pit sand, Thames sand and ground brick, the proportions of lime to aggregate in all cases being 1 to 3.

It was intended to obtain tests of the breaking strain at one and three months, as well as at twelve months and two years; but the strength of the mortar at those periods was too low, in consequence of insufficient setting, to enable reliable results to be obtained, the bricks in many cases coming apart in the process of fixing them in the testing machine.

The tests at twelve months and two years are set out in the Table and Diagram E, a, b, and c, and clearly indicate that in the case of the Fletton bricks the adhesive power is considerably greater than with the Stock bricks, the average results at the end of two years, in order of the aggregates given above, being—

TABLE IX

	Standard Sand.	Charlton Fine Sand.	Pit Sand.	Thames Sand.	Ground Brick.
Stock bricks	55	48	55	127	232 lb.
Fletton „	122	87	200	293	347 „

It is to be noted that the last three series, viz. pit and Thames sand and ground brick, in the case of the Fletton bricks particularly, the mortar adhered so firmly to the brick that it broke in itself instead of leaving the surface of the brick, as happened in all the tests which gave a lower result.

It is noteworthy that the ground brick mortar gave the maximum results in both cases.

SECTION X

TRASS

By the courtesy of Mr. William Challoner of Blackpool, I am enabled to add the following results of authoritative tests of mortars in which trass has been employed. It was intended to include a series of such tests, as well as others with pozzuolana, in the investigation, but the detailed work involved in connection with the large number of tests set out in the programme authorised by the committee rendered this impossible.

Fortunately, the work which has been done in Germany in connection with the use of trass, under stringent Government conditions, enables me to submit the following valuable information, and thus fill what would otherwise have been a serious blank.

The abstract of the interesting and valuable paper by M. J. Mund of Cologne, in 1908, very fully discusses the question, and gives many details of German practice. The standard specification for mortars and concretes adopted by the Royal Board of Railway Administration, Germany—Herr Kirchner, Engineer and Technical Secretary to the Board—dated July 17, 1910, will be read with interest.

It is to be noted that the lime used is a "fat" lime, similar to that obtained from Buxton limestone, and that the sand is Rhine sand, which is the normal sand used in Germany, graded to not more than 40 per cent. of voids.

When slacking, the lime is broken into pieces not larger than will pass a 5-inch ring, and the water is added slowly, the lime being constantly agitated, and no part of it allowed to become chilled or lower than 70° F. Mr. Challoner informs me that by this method he has obtained 25 per cent. more "putty" from a ton of lime than by the ordinary English "slutching" process.

TABLE X

TESTS OF LIME, MORTAR WITH TRASS

TENSILE TESTS, POUNDS PER SQUARE INCH

No. of Days.	Made by Herr Helbing, Engineer, Essen, Germany, in connection with the Flood Dams, etc., of the Ems Waterworks, March 30, 1906.		Made by Herr A. Unna, Engineer, Cologne.	
	Lime 1 vol. Trass 1 ,, Sand 1 ,,	Lime 3 vols. Trass 1 vol. Sand 6 vols.	Lime 1 vol. Trass 1 ,, Sand 1 ,,	Lime 1 vol. Trass 1½ vols. Sand 1 vol.
7 days	—	—	140	220
14 ,,	225	170	170	250
28 ,,	**323**	**268**	**240**	**300**
3 months	**370**	**400**	**330**	**380**
6 ,,	—	—	370	440
12 ,,	—	—	**380**	**455**
	Compression Tests, pounds per square inch.			
	Lime 1 vol. Trass 1½ vols. Sand 1¾ ,,	Lime 3 vols. Trass 1 vol. Sand 6 vols.		
14 days	980	1300		
28 ,,	**1400**	**1550**		
100 ,,	**2040**	**2250**		

Note.—The numbers in heavy type correspond, in time interval, to those in the committee's series.

TABLE XI

TRASS IN LIME AND MORTAR

TESTS OF TENSILE STRENGTH MADE BY MR. WILLIAM CHALLONER.

Time Interval.	Pounds per Square Inch.				
	Lime 1 vol. Trass 1½ vols. Sand 1 vol.	Lime 1 vol. Trass 1 ,, Sand 1 ,,	Lime 1 vol. Trass 1 ,, Sand 2 vols.	Lime 1 vol. Trass 1 ,, Sand 3 vols.	Lime 2 vols. Trass 1 vol. Sand 5 vols.
1 Day	10	25	7	10	2
2 Days . . .	18	45	16	20	8
3 ,, . . .	60	60	26	30	18
7 ,, . . .	223	108	80	95	70
14 ,, . . .	272	187	126	150	108
28 ,, . . .	**313**	**250**	**182**	**187**	**138**
3 Months . . .	**349**	**324**	**225**	**212**	**166**
6 ,, . . .	383	370	250	230	189
12 ,, . . .	**393**	**393**	**268**	**242**	**203**
2 Years . . .	**405**	**405**	**287**	**248**	**212**
3 ,, . . .	417	415	292	250	217

Note.—The numbers in heavy type correspond, in time interval, to those in the committee's series.

COLOGNE BRIDGE, 1847, UNDER WATER

1 vol. sand, 1 vol. slaked lime, 7½ vols. trass, received from Mr. William Challoner.

	Per cent.
Sand and grit	48·20
Sol. silica	9·70
Oxide of iron and alumina . .	7·55
CaO	14·55
MgO	0·46
CO_2	8·06
SO_3	nil
Water of hydration, etc. . . .	11·44
	99·96
Earthy matter (clay) . . .	2·45
Clay on sand	3·1
Character of mortar . . .	very hard

Too small in quantity for further tests.

TABLE XII

COPY AND TRANSLATION OF STANDARD SPECIFICATIONS FOR MORTARS AND CONCRETES ADOPTED BY ROYAL BOARD OF RAILWAY ADMINISTRATION, GERMANY

HERR KIRCHNER, *Engineer, Technical Secretary to the Board, Cologne, July* 17, 1910

The following are the tests of mortars and concretes used on new bridge over Rhine at Cologne, as per specification:—

		Tensile Strength in Kgs. per sq. Ctm.				Compressive Strength Kgs. cu. Ctm.			
Mortars—		7 Days	14	28	90	7 Days	14	28	90
No. 1	1 Trass, 1 Lime Putty, 3 Sand — This mortar is for the rubble walls of under-bridges and elevated masonry	6·8	13·25	18·4	23·1	54	101	121	161
No. 2	1 Trass, 1 Lime Putty, 2 Sand — Mortar for rubble masonry in retaining walls and other portions bearing large loads ...	7·5	13·62	19·1	24·2	56·4	104	133	192
No. 3	1 Trass, 1 Lime Putty, 1 Sand — Mortar for rubble retaining walls to bear greatest strength in foundations, etc. ...	9·58	14	20·5	27·91	65	109	268	249
No. 4	1 Trass, 1 Cement, 4 Sand — For purposes as 2 and 3, and for facing vaults of tunnels, butments of iron arch-work and all purposes where quick harden-ing is required	11	15·5	21	30	95	132	189	273
No. 4a	1 Trass, 1 Cement, 3 Sand — For facing work and rendering, and work submerged in water, to be rapidly finished	13	20	25	36	120	210	270	330
	Note.—In winter 8 per cent. additional cement to be added.								
No. 5	1 Trass, 1 Cement, 15 Gravel — For filling piers or haunches of bridges, both in water and superstructure	—	—	—	—	—	—	142	214

THE USE OF "TRASS" FOR MORTARS AND CONCRETES IN MODERN BUILDING CONSTRUCTION

Abstract of Paper read at the Sectional Meeting of the National Association of Technical Engineers of Germany by M. J. Mund, Cologne, 1908.

Translated and Edited by Mr. William Challoner.

THE great advantages to be derived from trass as an admixture for mortar is demonstrated in the only available practical manner by examples of ancient structures which still defy the ravages of time. These results we are able to show approximately by tests conducted by more or less artificial means in the laboratory, which by a careful selection of materials and accurate calculations of the proportions are very reliable when the experiments are carried out by men of trained experience in such work.

It is further desirable that the peculiar necessities of each class of work should be carefully considered in order to ensure permanent results, and that the laboratory tests should be made with the same materials and under the same conditions as exist on the actual work.

If these are not closely observed the information obtained from the tests will be of little practical value, or at any rate entirely misleading, as, for instance, if cement, lime, or trass be tested with aggregates dissimilar to those which will be ultimately employed in the actual work, or under conditions of humidity and temperature different from those which will then constitute their environment.

It must also be borne in mind that although the binding materials, cement, lime, and trass may be of the highest quality, the resultant mixture of mortar may be inferior, or even useless, owing to an absence of requisite care in the selection, proportioning, or grading of the sand and stone which form the aggregates, and incidentally, perhaps, the largest proportion of the mixture.

A great impetus has been given to the use of trass in building mortars by the appointment, some twenty-five years ago, of a commission which represented leading engineers and architects, cement manufacturers, lime and trass quarry owners.

This commission was subsidised by the Government, and is in connection with the Royal Experimental Institute of Charlottenburg. Amongst its principal objects were those of dealing in a practical manner with the important matter of building materials on the lines indicated above, and in addition to prevent the erroneous deductions which may be obtained from tests carried out in a manner less in accordance with actual conditions.

The use of trass in mortar and concrete had been general for engineering construction work both under water and below ground for foundations, and the attention of the commission was now directed to the advantages which it offered over the existing practice by its use as an admixture for mortar in the superstructure.

To this end the specifications, which lacked detail in other respects, were revised, and a series of careful tests made on new lines which gave interesting and successful results.

As a consequence, leading building engineers and architects of public works adopted these revised specifications for mortars, with such modifications as were suited to the peculiar necessities of condition and environment.

The chief points for consideration in arranging the specifications for mortar are strength, density, permanency, and economy in cost; at the same time due regard must be paid to the quality and form of the aggregates which are available in the locality.

From amongst many public buildings the following are submitted, for which specifications for mortars were drawn up in accordance with the results of the tests referred to, trass with fat lime being substituted for the hydraulic and other more or less impure limes it had formerly been the practice to use:—

New Post Office, Cologne, 1892.
Law Courts, Cologne, 1893.
Library and Record Office, 1894.

For these collectively, some 3000 tons of trass were used.

The Government architects of the above buildings, M. Brugger and Trimborn respectively, have kindly supplied copies of specifications and comparisons of cost for the different mortars used on the work, and they have expressed their unqualified approval of results obtained.

The specification of mortar for the whole of the Library and Record Office, of which M. Brugger was architect, is as follows—

1 volume of trass,
2 volumes fat lime putty,
5 volumes sand.

This mixture possessed the highest efficiency in point of strong density and cheapness as compared with the mortar composed of—

1 volume hydraulic lime,
2½ vols. sand,

which was the specification formerly in general use for the same class of building.

In the New Post Office and Law Courts, of which M. Trimborn was architect, the specification was varied in respect to proportion of sand, but no hydraulic lime was used for either foundations or superstructure; for these works the following specification was adopted—

1 volume of trass,
1 volume of fat lime,
3 to 4 vols. of sand,

In a communication the architect states: "The walls built with this mortar are excessively strong, and the admixture of trass in the mortar gave much better results than could have been obtained by the use of hydraulic lime or cement for the same purpose."

For the building of the Gas Works for the town of Mulheim, the Government architect, M. Rathke, used similar specifications, the mortar being composed of equal volumes of fat lime and trass to 3 vols. of sand. M. Rathke reports that the mortar gave results in every way superior to mortar that contained hydraulic lime.

In the foregoing illustrations there existed no abnormal difficulties due to wet ground, and therefore a mortar of a high degree of density was unnecessary.

Where, however, wet ground is encountered, it is necessary to use a mortar of a higher degree of density, and the following proportions have been found the most suitable in order to secure an absolutely watertight mixture—

1 volume trass,
1 volume fat lime,
1 to 1½ sand.

It is well known to architects and builders that in cases where the mortar is not well flushed, percolation of water, either under slight pressure or by capillary attraction, usually takes place by way of the joints; also that the use of dense insoluble stone of a porous nature or badly burnt bricks would not be allowed.

Owing to the natural conditions of low-water-bearing ground, the Dutch architects and builders have long realised the necessity for a careful selection of impervious building materials, and for the preparation of dense insoluble mortars; for that reason hard burnt bricks and trass lime mortars have been in common use in Holland for centuries.

Most of the buildings in Haarlem, Rotterdam, Amsterdam and The Hague are evidence of the success which has attended this practice, as although nearly all the buildings have their foundations below normal water level, they show few signs of dampness or depreciation due to this cause.

The new Railway Station at Amsterdam may be taken as an example of a recent building on which mortar that contained trass has been used.

The volumes of lime and trass are varied proportionately to meet the necessities of the varying degrees of moisture to which the foundations must be subjected, and the proportions of the two former ingredients are reduced for the superstructure, where a less dense mortar will fulfil the required conditions of strength to maintain the stability of the building while at the same time effecting an economy in cost.

It may be suggested that some of the proved advantages of trass lime mortar may be obtained by the use of Portland cement mortar, but it is unnecessary to point out that the theoretical advantages of cement mortar are entirely discounted by the difficulties attending its use in actual practice. If the mortar is sufficiently rich in Portland cement, it cannot be spread unless water is continually added, and the stones or bricks must also be kept wetted to prevent the water from the mortar being absorbed. The result is that very little of the cement eventually remains in the mortar. This absorption does not take place in trass lime or even trass cement mortars.

SECTION XI

SUMMARISED CONCLUSIONS

WHILST there are many points of interest which a study of the tables and diagrams bring to light, it will be sufficient for the present purpose to indicate those of a more prominent character in a semi-tabulated form for convenience of reference.

The diagrammatic expression of results shows clearly the absolute necessity for tests of this nature to be carried out over a fairly prolonged period. Probably the full period of two years adopted by the committee is ample for the purpose of comparative results, in order that the effect of moisture in the mortar may, as far as is practicable, be eliminated. In many cases, what I have termed the "time sequence" shows clearly that when a mortar is new or "green" it will have a greater strength than when dried, the effect of the moisture being to exert a capillary attraction, and thus give a false strength which is not maintained later on. The fact that the irregular "time sequence" appears practically only in cases of mortars of distinctly inferior quality is of no little interest.

The effect of different sands is very varied. Fine Charlton sand gave its best results with white chalk lime, and its worst with blue lias lime, whilst the addition of clay was distinctly detrimental. On the other hand, the coarser sands, Thames and pit, gave far better results with the lias lime than with the chalk limes, and with these sands no advantage was obtained by the addition of clay; but when this material was added in the proportion of 5 per cent. to standard sand used with blue lias lime in the proportions of 1 lime to 3 sand, the strength rose to the highest of any obtained in the series. It would thus seem that, given good materials, the essential point is to completely fill the voids, as it cannot be assumed that the addition of such a small quantity of clay could of itself raise the strength of the mortar over four and a half times.

An interesting feature of the tests consists of the results set out in Section V, from which can be ascertained what matrix or aggregate should be preferred for use with either one or the other to secure the best results. If a Dorking greystone lime is employed, pit sand in the ratio of 1 to 2 will give the maximum crushing strength, equal to double that obtained with Charlton fine sand, and clay should not be present. If the lime is blue lias, ground brick is preferable in the ratio of 1 to 2, which gives nearly four times the strength available with fine sand. If a given lime and sand are to be employed, say Dorking greystone lime and ordinary pit sand, the usual proportion of 1 to 3 is not so good as 1 to 2, which gives a crushing strength of half as much again, with only a very little lower tensile strength.

It is unfortunate that the tests with clay added to the aggregate were confined to proportions of 1 to 3 in all cases, as there is ample reason for concluding that if these had been made with proportions of 1 to 2, very much better results would have been obtained.

The ratios of tensile to crushing strength are distinctly variable, and do not appear to convey any marked indication of value.

The examination of ancient mortars presents features of peculiar interest. In the first instance they distinctly point to the absence of the formation of soluble silica, which it has been assumed was formed in the course of time by the action of the lime in sand—a mistake undoubtedly arising from the presence of pozzuolana in ancient mortars.

Another point is that the presence of clean ferruginous clay has certainly had no deleterious effect, this being present in quantities up to 8 per cent. on the sand in some of the finest samples examined.

These examinations further give rise to the question as to the wisdom of the assumed propriety of the proportions of 1 to 3, so generally recommended at the present time, as nearly all the best old mortars contained proportions of 1 to 1, to 1 to 2, which agrees with the conclusions now experimentally demonstrated that larger proportions of matrix than 1 to 3 give better results.

The tests for adhesion of bricks with various mortars clearly demonstrated the superiority of Fletton bricks over Stock bricks, and the distinct inferiority of standard sand, Charlton fine and pit sand, compared with Thames sand and ground brick as aggregates.

The details of the respective tests are fully set out in the attached Tables XIII to XIX and the accompanying Diagrams.

W. J. Dibdin.

February 1911.

SECTION XII

TABLE XIII

Series A. White Chalk Lime (95 % CaO)

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
With Standard Sand (Leighton Buzzard).								
Aa.					***Aa'.***			
1 Lime 2 Sand	20	40	58	40	63	170	230	270
,, ,,	20 } 23	35 } 38	50 } 54	45 } 43	115 } 85	185 } 175	190 } 210	225 } 218
,, ,,	30	38	?	45	78	169	210	160
1 Lime 3 Sand	30	34	54	50	75	266	330	285
,, ,,	28 } 26	42 } 38	50 } 50	55 } 53	116 } 122	235 } 267	325 } 308	240 } 240
,, ,,	20	37	46	55	175	300	270	195
1 Lime 4 Sand	20	80	68	60	153	165	230	120
,, ,,	80 } 50	60 } 68	64 } 66	75 } 65	125 } 166	234 } 194	230 } 212	235 } 223
,, ,,	50	65	?	60	219	184	175	315
1 Lime 5 Sand	35	56	66	20	41	62	140	45
,, ,,	20 } 28	72 } 58	55 } 59	60 } 40	31 } 44	25 } 51	70 } 93	45 } 45
,, ,,	30	45	55	?	59	66	70	?
With Fine Sand (Charlton).								
Ab.					***Ab'.***			
1 Lime 2 Sand	35	52	90	80	200	222	350	250
,, ,,	30 } 30	45 } 56	100 } 92	45 } 53	78 } 139	319 } 323	330 } 338	350 } 300
,, ,,	25	72	86	40	138	428	335	?
1 Lime 3 Sand	20	50	48	40	104	212	240	275
,, ,,	20 } 25	42 } 44	82 } 70	60 } 55	116 } 116	241 } 201	275 } 231	235 } 260
,, ,,	35	40	80	65	129	150	178	270
1 Lime 4 Sand	30	90	88	60	175	293	260	260
,, ,,	30 } 28	84 } 85	88 } 86	70 } 60	169 } 167	216 } 257	275 } 278	200 } 217
,, ,,	25	80	82	50	157	262	300	190
1 Lime 5 Sand	30	40	50	40	142	190	190	105
,, ,,	45 } 37	40 } 44	44 } 46	25 } 32	75 } 114	103 } 135	165 } 160	80 } 88
,, ,,	35	52	44	?	125	112	125	80

TABLE XIII (*continued*)

SERIES A (*continued*). WHITE CHALK LIME (95 per cent. CaO)

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
Ac.					***Ac'.***			
With Pit Sand (ordinary).								
1 Lime 2 Sand	20	38	90	70	160	206	472	300
,, ,,	25 } 20	52 } 44	90 } 89	75 } 73	131 } 142	191 } 197	304 } 385	240 } 247
,, ,,	15	42	88	75	134	194	380	200
1 Lime 3 Sand	27	40	72	50	221	300	380	260
,, ,,	10 } 16	40 } 42	50 } 61	40 } 50	181 } 177	240 } 243	250 } 297	240 } 253
,, ,,	10	46	62	60	130	189	260	260
1 Lime 4 Sand	20	30	50	50	180	222	160	170
,, ,,	24 } 18	38 } 35	50 } 49	60 } 53	66 } 113	153 } 207	260 } 233	170 } 170
,, ,,	10	38	46	50	94	247	280	170
1 Lime 5 Sand	32	45	56	55	128	200	185	230
,, ,,	30 } 31	55 } 56	62 } 60	50 } 55	177 } 144	197 } 177	180 } 200	220 } 193
,, ,,	32	68	62	60	127	135	235	130
With Thames Sand.								
Ad.					***Ad'.***			
1 Lime 2 Sand	27	50	125	90	157	222	418	300
,, ,,	27 } 27	65 } 59	105 } 101	100 } 100	140 } 166	272 } 240	265 } 406	310 } 297
,, ,,	27	62	72	110	202	225	535	280
1 Lime 3 Sand	20	62	70	75	203	215	287	230
,, ,,	30 } 20	52 } 58	60 } 65	70 } 68	135 } 147	218 } 238	235 } 257	220 } 202
,, ,,	10	60	?	60	103	282	250	155
1 Lime 4 Sand	22	48	52	70	158	218	335	230
,, ,,	22 } 26	48 } 57	56 } 61	75 } 68	172 } 157	396 } 325	340 } 342	305 } 275
,, ,,	35	75	74	60	140	362	350	290
1 Lime 5 Sand	30	65	70	50	193	378	318	245
,, ,,	25 } 31	65 } 67	64 } 67	70 } 60	241 } 215	307 } 320	346 } 331	270 } 235
,, ,,	37	70	66	60	212	275	330	190

TABLE XIII (*continued*)

SERIES A (*continued*). WHITE CHALK LIME (95 per cent. CaO)

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
With Ground Brick.								
	Ae.				*Ae'.*			
1 Lime 2 Brick	24	37	56	50	194	287	308	265
,, ,,	30 } 26	42 } 39	70 } 66	60 } 60	141 } 146	350 } 309	155 } 241	175 } 213
,, ,,	24	37	72	70	103	291	260	200
1 Lime 3 Brick	12	27	55	40	231	166	240	210
,, ,,	12 } 17	47 } 40	52 } 47	40 } 40	153 } 159	319 } 240	138 } 215	415 } 312
,, ,,	28	45	34	40	93	234	268	310
1 Lime 4 Brick	32	40	60	50	223	239	215	165
,, ,,	34 } 32	45 } 41	58 } 57	30 } 38	108 } 156	232 } 219	265 } 223	280 } 222
,, ,,	30	38	52	35	137	187	190	?
1 Lime 5 Brick	36	60	60	50	150	227	125	180
,, ,,	35 } 34	50 } 53	56 } 61	55 } 52	145 } 154	162 } 205	228 } 233	160 } 152
,, ,,	30	50	66	50	166	227	345	105

SECTION XIII

TABLE XIV

Series B. Dorking Greystone Lime

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
With Standard Sand (*Leighton Buzzard*).								
Ba.					**Ba'.**			
1 Lime 2 Sand	20	50	60	100	175	215	440	235
,, ,,	10 } 18	40 } 43	80 } 70	100 } 97	91 } 153	269 } 220	335 } 360	305 } 257
,, ,,	25	40	70	90	192	175	305	230
1 Lime 3 Sand	35	65	85	100	155	156	285	270
,, ,,	35 } 38	60 } 63	75 } 80	105 } 103	141 } 127	162 } 189	265 } 263	210 } 228
,, ,,	45	65	80	105	86	250	240	205
1 Lime 4 Sand	35	20	35	35	85	81	100	85
,, ,,	35 } 34	35 } 30	20 } 28	30 } 32	83 } 80	94 } 92	100 } 95	120 } 92
,, ,,	32	34	20	30	71	100	85	70
1 Lime 5 Sand	42	28	50	30	31	28	37	50
,, ,,	28 } 34	35 } 31	45 } 47	25 } 27	50 } 47	36 } 31	38 } 38	50 } 48
,, ,,	32	30	?	?	60	28	40	45
With Fine Sand (*Charlton*).								
Bb.					**Bb'.**			
1 Lime 2 Sand	20	20	50	50	93	109	140	130
,, ,,	30 } 20	25 } 23	45 } 42	55 } 50	119 } 96	137 } 134	135 } 136	155 } 143
,, ,,	10	25	30	45	75	156	132	145
1 Lime 3 Sand	28	34	45	35	128	119	130	150
,, ,,	20 } 23	28 } 31	30 } 35	35 } 35	101 } 120	141 } 129	140 } 135	150 } 140
,, ,,	22	30	30	35	131	126	?	120
1 Lime 4 Sand	20	28	37	35	163	69	85	150
,, ,,	15 } 17	20 } 25	35 } 36	30 } 32	131 } 147	87 } 70	110 } 108	110 } 130
,, ,,	16	26	36	30	147	53	130	130
1 Lime 5 Sand	26	35	30	20	175	100	140	200
,, ,,	26 } 26	35 } 35	40 } 35	25 } 27	131 } 148	137 } 123	120 } 130	160 } 180
,, ,,	26	35	36	35	138	131	130	180

TABLE XIV (*continued*)

SERIES B (*continued*). DORKING GREYSTONE LIME

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
With Pit Sand (ordinary) **Bc.**					**Bc'.**			
1 Lime 2 Sand	44	70	65	60	202	295	330	320
,, ,,	30 } 36	50 } 65	70 } 73	65 } 62	213 } 201	241 } 254	320 } 360	345 } 333
,, ,,	35	74	85	60	187	226	430	335
1 Lime 3 Sand	35	54	80	70	171	175	220	190
,, ,,	35 } 30	52 } 55	72 } 72	70 } 75	231 } 213	250 } 216	240 } 232	220 } 200
,, ,,	20	60	65	85	237	222	235	190
1 Lime 4 Sand	31	42	68	90	170	183	180	140
,, ,,	30 } 32	55 } 46	88 } 77	50 } 67	122 } 162	228 } 202	250 } 210	190 } 203
,, ,,	35	40	75	60	195	194	200	280
1 Lime 5 Sand	30	58	74	75	148	153	200	225
,, ,,	30 } 33	72 } 66	62 } 67	60 } 60	123 } 137	172 } 184	235 } 245	225 } 220
,, ,,	40	68	65	45	141	228	300	210
With Thames Sand **Bd.**					**Bd'.**			
1 Lime 2 Sand	55	72	80	85	147	213	210	190
,, ,,	46 } 48	64 } 69	80 } 83	85 } 88	195 } 160	200 } 208	305 } 240	300 } 243
,, ,,	42	70	90	95	137	212	205	240
1 Lime 3 Sand	55	72	65	60	229	544	270	220
,, ,,	32 } 37	60 } 67	50 } 57	65 } 58	224 } 223	444 } 430	310 } 323	205 } 228
,, ,,	25	68	55	50	217	303	390	260
1 Lime 4 Sand	58	84	65	85	229	197	280	180
,, ,,	54 } 55	95 } 95	85 } 73	90 } 85	303 } 277	200 } 198	168 } 209	240 } 198
,, ,,	54	105	70	80	300	197	180	175
1 Lime 5 Sand	38	40	50	40	170	170	188	155
,, ,,	35 } 38	55 } 46	55 } 52	35 } 37	172 } 180	128 } 140	150 } 169	155 } 137
,, ,,	40	42	52	35	197	122	170	100

TABLE XIV (*continued*)

SERIES B (*continued*). DORKING GREYSTONE LIME

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
With Ground Brick.								
Be.					***Be'.***			
1 Lime 2 Sand	30	50	56	35	344	119	138	130
,, ,,	10 } 23	35 } 42	48 } 51	40 } 38	67 } 187	225 } 171	160 } 133	100 } 123
,, ,,	30	40	48	40	150	169	100	140
1 Lime 3 Sand	48	35	55	25	03	97	112	190
,, ,,	34 } 41	38 } 41	48 } 51	30 } 27	12 } 100	97 } 122	155 } 129	105 } 162
,, ,,	40	50	51	25	84	172	120	190
1 Lime 4 Sand	34	56	58	55	94	97	265	120
,, ,,	48 } 41	42 } 47	68 } 60	50 } 48	116 } 104	94 } 97	140 } 173	135 } 130
,, ,,	42	42	54	40	103	100	115	135
1 Lime 5 Sand	20	38	46	45	178	134	210	140
,, ,,	28 } 27	30 } 39	55 } 50	30 } 38	164 } 165	147 } 168	140 } 163	160 } 142
,, ,,	32	50	50	40	153	223	140	125

SECTION XIV

TABLE XV

Series C. Blue Lias Lime from Nelson's, Stockton, near Rugby

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
With Standard Sand (*Leighton Buzzard*).								
Ca.					***Ca′.***			
1 Lime 2 Sand	40	60	50	60	288	365	560	615
,, ,,	42 } 41	80 } 63	55 } 62	55 } 58	218 } 280	400 } 372	335 } 447	450 } 538
,, ,,	40	50	80	60	335	350	?	550
1 Lime 3 Sand	58	25	20	20	115	230	155	230
,, ,,	50 } 44	15 } 18	20 } 18	40 } 38	118 } 134	235 } 193	145 } 147	185 } 188
,, ,,	25	15	14	55	170	115	140	150
1 Lime 4 Sand	15	15	5	12	88	200	140	137
,, ,,	15 } 15	10 } 15	35 } 20	12 } 11	122 } 95	100 } 153	150 } 120	165 } 150
,, ,,	15	20	20	10	76	160	70	148
1 Lime 5 Sand	15	20	30	12	125	235	155	170
,, ,,	30 } 28	35 } 27	20 } 23	38 } 19	118 } 133	155 } 187	140 } 135	183 } 198
,, ,,	38	27	20	8	156	170	110	240
With Fine Sand (*Charlton*).								
Cb.					***Cb′.***			
1 Lime 2 Sand	37	30	40	37	96	160	325	220
,, ,,	27 } 29	45 } 42	45 } 42	40 } 40	90 } 92	145 } 160	370 } 332	230 } 257
,, ,,	24	50	40	42	90	175	300	320
1 Lime 3 Sand	15	20	20	25	108	160	150	164
,, ,,	15 } 13	20 } 20	25 } 23	27 } 26	80 } 90	190 } 172	185 } 182	145 } 156
,, ,,	10	20	25	25	82	165	210	160
1 Lime 4 Sand	17	10	15	22	80	70	140	145
,, ,,	15 } 18	25 } 18	15 } 13	18 } 20	71 } 70	100 } 89	145 } 157	105 } 133
,, ,,	21	20	10	20	58	96	185	150
1 Lime 5 Sand	17	15	10	15	50	90	120	108
,, ,,	10 } 15	20 } 18	15 } 13	20 } 17	50 } 54	120 } 87	105 } 112	90 } 98
	17	20	15	17	62	50	110	95

TABLE XV (*continued*)

SERIES C (*continued*). BLUE LIAS LIME FROM NELSON'S, STOCKTON, NEAR RUGBY

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
With Pit Sand (ordinary).								
Cc.					***Cc'.***			
1 Lime 2 Sand	23	75	65	95	275	380	670	690
,, ,,	55 } 38	35 } 58	65 } 73	80 } 75	230 } 285	240 } 337	625 } 542	530 } 605
,, ,,	35	65	90	50	350	390	330	595
1 Lime 3 Sand	40	45	75	90	185	250	440	590
,, ,,	55 } 50	60 } 57	95 } 77	90 } 77	260 } 222	420 } 367	560 } 500	615 } 650
,, ,,	55	65	60	50	220	430	500	745
1 Lime 4 Sand	60	50	75	56	150	270	435	557
,, ,,	43 } 51	45 } 58	60 } 67	65 } 60	210 } 195	430 } 333	540 } 450	540 } 548
,, ,,	50	80	65	60	225	300	375	?
1 Lime 5 Sand	35	50	40	35	155	230	190	325
,, ,,	38 } 39	45 } 45	35 } 35	50 } 42	158 } 148	290 } 260	310 } 260	250 } 303
,, ,,	43	40	30	40	132	260	280	335
With Thames Sand								
Cd.					***Cd'.***			
1 Lime 2 Sand	55	65	55	65	470	510	655	810
,, ,,	52 } 51	60 } 63	70 } 58	75 } 80	335 } 407	510 } 510	750 } 732	690 } 785
,, ,,	45	65	50	100	415	510	790	855
1 Lime 3 Sand	62	105	100	105	300	550	595	420
,, ,,	62 } 64	60 } 82	100 } 97	80 } 102	210 } 247	360 } 463	520 } 558	560 } 507
,, ,,	68	80	90	120	230	480	560	540
1 Lime 4 Sand	65	60	80	70	258	310	350	395
,, ,,	53 } 63	45 } 57	90 } 75	80 } 76	270 } 269	260 } 287	595 } 458	420 } 430
,, ,,	70	65	55	78	280	290	430	475
1 Lime 5 Sand	55	50	20	40	180	150	175	370
,, ,,	45 } 45	55 } 55	40 } 37	50 } 45	125 } 162	230 } 218	220 } 202	205 } 275
,, ,,	35	60	50	45	180	275	210	250

TABLE XV (*continued*)

SERIES C (*continued*). BLUE LIAS LIME FROM NELSON'S, STOCKTON, NEAR RUGBY

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
With Ground Brick								
	Ce				*Ce'*.			
1 Lime 2 Sand	100	105	120	120	580	740	810	820
,, ,,	90 } 98	100 } 103	125 } 118	120 } 133	470 } 525	450 } 587	650 } 730	1050 } 910
,, ,,	103	105	110	160	525	570	?	860
1 Lime 3 Sand	90	65	85	95	615	540	?	630
,, ,,	80 } 78	75 } 78	90 } 85	60 } 87	228 } 466	535 } 542	600 } 625	640 } 657
,, ,,	63	95	80	105	555	550	650	700
1 Lime 4 Sand	73	105	85	100	522	400	510	570
,, ,,	95 } 87	90 } 95	80 } 78	75 } 95	348 } 464	620 } 528	555 } 560	580 } 568
,, ,,	93	90	70	110	522	565	615	555
1 Lime 5 Sand	113	75	90	80	492	505	495	645
,, ,,	125 } 113	85 } 90	90 } 87	105 } 93	466 } 461	435 } 473	440 } 502	530 } 610
,, ,,	100	110	80	95	424	480	570	655

SECTION XV

TABLE XVI

SERIES D. MORTARS CONTAINING 5 PER CENT. OF RED LONDON CLAY, calculated on the dry mortar, the sand being first mixed with the clay

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
Lime used—White Chalk **Da.**					***Da'.***			
With Standard Sand (Leighton Buzzard)								
1 Lime 3 Sand	20	40	72	45	119	247	270	230
,, ,,	28 } 24	38 } 42	78 } 77	55 } 50	168 } 134	219 } 231	325 } 298	220 } 230
,, ,,	25	48	82	50	114	228	300	240
With Fine Sand (Charlton)								
1 Lime 3 Sand	22	36	62	40	68	109	105	60
,, ,,	20 } 21	38 } 37	65 } 64	30 } 35	83 } 70	119 } 104	140 } 112	70 } 70
,, ,,	20	38	64	35	59	84	92	80
With Pit Sand (ordinary)								
1 Lime 3 Sand	38	40	80	60	53	187	125	115
,, ,,	25 } 31	36 } 35	86 } 85	60 } 57	44 } 45	144 } 149	110 } 140	180 } 163
,, ,,	30	30	90	50	39	116	185	195

TABLE XVI (*continued*)

SERIES D (*continued*). MORTARS CONTAINING FIVE PER CENT. OF RED LONDON CLAY calculated on the dry mortar, the sand being first mixed with the clay

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
Lime used—	*Dorking Greystone.*				*Db'.*			
Db.								
With Standard Sand (Leighton Buzzard)								
1 Lime 3 Sand	29	60	70	45	125	109	130	170
,, ,,	25 } 27	62 } 57	75 } 72	50 } 48	159 } 134	166 } 165	155 } 133	170 } 177
,, ,,	28	50	70	50	119	219	115	190
With Fine Sand (Charlton)								
1 Lime 3 Sand	18	28	50	20	47	87	68	70
,, ,,	18 } 15	30 } 28	40 } 43	20 } 20	41 } 49	97 } 84	68 } 68	95 } 82
,, ,,	10	26	40	?	58	69	68	?
With Pit Sand (ordinary)								
1 Lime 3 Sand	40	74	90	70	64	134	148	160
,, ,,	42 } 37	60 } 71	70 } 77	60 } 67	72 } 80	244 } 191	228 } 188	120 } 140
,, ,,	28	80	70	70	103	194	188	?

TABLE XVI (*continued*)

SERIES D (*continued*). MORTARS CONTAINING 5 % OF RED LONDON CLAY, calculated on the dry mortar, the sand being first mixed with the clay

	Tensile Strength.				Crushing Strength.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
Lime used—	*Blue Lias.*							
Dc.					***Dc'.***			
With Standard Sand (Leighton Buzzard)								
1 Lime 3 Sand	50	135	145	148	208	430	650	805
,, ,,	52 } 51	140 } 142	120 } 125	225 } 168	175 } 174	610 } 563	630 } 637	956 } 876
,, ,,	52	150	110	130	140	650	630	868
With Fine Sand (Charlton)								
1 Lime 3 Sand	15	30	25	48	40	78	50	90
,, ,,	10 } 13	40 } 33	25 } 27	20 } 34	28 } 37	60 } 69	70 } 73	82 } 79
,, ,,	14	30	30	?	42	70	100	65
With Pit Sand (ordinary)								
1 Lime 3 Sand	40	105	75	152	170	440	480	600
,, ,,	25 } 30	70 } 87	105 } 93	95 } 121	162 } 177	500 } 500	680 } 517	500 } 550
,, ,,	25	85	100	115	200	560	390	?

SECTION XVI

TABLE XVII

Series G. Comparison of Mortars made with and without the Addition of Clay
Tensile Strength

	Mortar made *without* addition of Clay.				Mortar made *with* addition of 5 % Clay			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
Ga.								
Lime used—White Chalk.								
With Standard Sand								
1 Lime 3 Sand	30	34	54	50	20	40	72	45
,, ,,	28 } 26	42 } 38	50 } 50	55 } 53	28 } 24	38 } 42	78 } 77	55 } 50
,, ,,	20	37	46	55	25	48	82	50
With Fine Sand (Charlton)								
1 Lime 3 Sand	20	50	48	40	22	36	62	40
,, ,,	20 } 25	42 } 44	82 } 70	60 } 55	20 } 21	38 } 37	65 } 64	30 } 35
,, ,,	35	40	80	65	20	38	64	35
With Pit Sand (ordinary)								
1 Lime 3 Sand	27	40	72	50	25	40	80	60
,, ,,	10 } 16	40 } 42	50 } 61	40 } 50	30 } 31	36 } 35	86 } 85	60 } 57
,, ,,	10	46	62	60	38	30	90	50
Gb.								
Lime used—Dorking Greystone.								
With Standard Sand								
1 Lime 3 Sand	35	65	85	100	29	60	70	45
,, ,,	35 } 38	60 } 63	75 } 80	105 } 103	25 } 27	62 } 57	75 } 72	50 } 48
,, ,,	45	65	80	105	28	50	70	50
With Fine Sand (Charlton)								
1 Lime 3 Sand	28	28	45	35	18	28	50	20
,, ,,	20 } 23	30 } 31	30 } 35	35 } 35	18 } 15	30 } 28	40 } 43	20 } 20
,, ,,	22	34	30	35	10	26	40	?
With Pit Sand (ordinary)								
1 Lime 3 Sand	35	54	80	70	40	74	90	70
,, ,,	35 } 30	52 } 55	72 } 72	70 } 75	42 } 37	60 } 71	70 } 77	60 } 67
,, ,,	20	60	65	85	28	80	70	70

TABLE XVII (*continued*)

SERIES G (*continued*). COMPARISON OF MORTARS MADE WITH AND WITHOUT THE ADDITION OF CLAY

TENSILE STRENGTH

	Mortar made *without* addition of Clay.				Mortar made *with* addition of 5 % Clay.			
	1 Month	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
Gc.								
Lime used—	*Blue Lias.*							
With Standard Sand								
1 Lime 3 Sand	58	25	20	20	50	135	145	148
,, ,,	50 } 44	15 } 18	20 } 18	40 } 38	52 } 51	140 } 142	120 } 125	225 } 168
,, ,,	25	15	14	55	52	150	110	130
With Fine Sand (Charlton)								
1 Lime 3 Sand	15	20	20	25	15	30	25	48
,, ,,	15 } 13	20 } 20	25 } 23	27 } 26	10 } 13	40 } 33	25 } 27	20 } 34
,, ,,	10	20	25	25	14	30	30	?
With Pit Sand (ordinary)								
Lime 3 Sand	40	45	75	90	40	105	75	152
,, ,,	55 } 50	60 } 57	95 } 77	90 } 77	25 } 30	70 } 87	105 } 93	95 } 121
,, ,,	55	65	60	50	25	85	100	115

TABLE XVIII

SERIES G′. COMPARISON OF MORTARS MADE WITH AND WITHOUT THE ADDITION OF CLAY

CRUSHING STRENGTH

	Mortar made *without* addition of Clay.				Mortar made *with* addition of 5 % Clay.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
Ga′.								
Lime used—White	*Chalk Lime*							
With Standard Sand								
1 Lime 3 Sand	75	266	330	285	119	247	270	230
,, ,,	116 } 122	235 } 267	325 } 308	240 } 240	168 } 134	219 } 231	325 } 298	220 } 230
,, ,,	175	300	270	195	114	228	300	240
With Fine Sand (Charlton)								
1 Lime 3 Sand	104	212	240	275	68	109	105	60
,, ,,	116 } 116	241 } 201	275 } 231	235 } 260	83 } 70	119 } 104	140 } 112	70 } 70
,, ,,	129	150	178	270	59	84	92	80
With Pit Sand (ordinary)								
1 Lime 3 Sand	221	300	380	260	53	187	125	115
,, ,,	181 } 177	240 } 243	250 } 297	240 } 253	44 } 45	144 } 149	110 } 140	180 } 163
,, ,,	130	189	260	260	39	116	185	195
Gb′.								
Lime used—Dorking	*Greystone*							
With Standard Sand								
1 Lime 3 Sand	155	156	285	270	125	109	130	170
,, ,,	141 } 127	162 } 189	265 } 263	210 } 228	159 } 134	166 } 165	155 } 133	170 } 177
,, ,,	86	250	240	205	119	219	115	190
With Fine Sand (Charlton)								
1 Lime 3 Sand	128	119	130	150	47	87	68	70
,, ,,	101 } 120	141 } 129	140 } 135	150 } 140	41 } 49	97 } 84	68 } 68	95 } 82
,, ,,	131	126	—	120	58	69	68	?
With Pit Sand (ordinary)								
1 Lime 3 Sand	171	175	220	190	64	134	148	160
,, ,,	231 } 213	250 } 216	240 } 232	220 } 200	72 } 80	244 } 191	228 } 188	120 } 140
,, ,,	237	222	235	190	103	194	188	?

TABLE XVIII (*continued*)

SERIES G′ (*continued*). COMPARISON OF MORTARS MADE WITH AND WITHOUT THE ADDITION OF CLAY

CRUSHING STRENGTH

	Mortar made *without* addition of Clay.				Mortar made *with* addition of 5 °/₀ Clay.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
Gc′. *Lime used—Blue Lias*								
With Standard Sand								
1 Lime 3 Sand	118	230	155	230	175	430	650	805
,, ,,	115 } 134	235 } 193	145 } 147	185 } 188	208 } 174	610 } 563	630 } 637	956 } 876
,, ,,	170	115	140	150	140	650	630	868
With Fine Sand (Charlton)								
1 Lime 3 Sand	108	160	150	164	40	78	50	90
,, ,,	80 } 90	190 } 172	185 } 182	145 } 156	28 } 37	60 } 69	70 } 73	82 } 79
,, ,,	82	165	210	160	42	70	100	65
With Pit Sand (ordinary)								
1 Lime 3 Sand	185	250	440	590	170	440	480	600
,, ,,	260 } 222	420 } 367	560 } 500	615 } 650	162 } 177	500 } 500	680 } 517	500 } 550
,, ,,	220	430	500	745	200	560	390	?

SECTION XVII

TABLE XIX

Series E, F. Brick Tests for Adhesion

	E Stocks.				F Flettons.			
	1 Month.	3 Months.	12 Months.	2 Years.	1 Month.	3 Months.	12 Months.	2 Years.
Dorking Greystone Lime.								
Ea.					***Fa.***			
1 vol. Lime 3 vols. Standard Sand	*Note.*—The 1 Month tests were abandoned, as the mortar was not sufficiently set to allow the bricks to be handled with safety.	*Note.*—The 3 Months' tests were abandoned, owing to the mortar being insufficiently set.	—	Broke in fixing 55 Broke in fixing } 55	See under	Notes "Stocks."	—	45 130 190 } 122
,, ,, ,, ,,								
,, ,, ,, ,,								
Eb.					***Fb.***			
1 vol. Lime 3 vols. Fine Sand			40 97 62 } 66	30 35 80 } 48	—	—	4 148 125 } 156	70 95 95 } 87
,, ,, ,, ,,								
,, ,, ,, ,,								
Ec.					***Fc.***			
1 vol. Lime 3 vols. Pit Sand			70 50 ? } 60	4 broke at less than testing strain 50 60 } 55	—	—	215 150 162 } 176	270* 340* 158* 100 180* 155 } 200
,, ,, ,, ,,								
,, ,, ,, ,,								
Ed.					***Fd.***			
1 vol. Lime 3 vols. Thames Sand			136 100 110 } 115	110 145* } 127 Several broke in handling on machine	—	—	276 200 250 } 242	333* 308* 314* 242* 268* } 293
,, ,, ,, ,,								
,, ,, ,, ,,								
Ee.					***Fe.***			
1 vol. Lime 3 vols. Ground Brick			155 140 216 } 170	225 240 ? } 232	—	—	225 520 310 } 352	310* 395* 335* } 347
,, ,, ,, ,,								
,, ,, ,, ,,								

* In these cases the mortar adhered to the surface of the brick and broke in itself.

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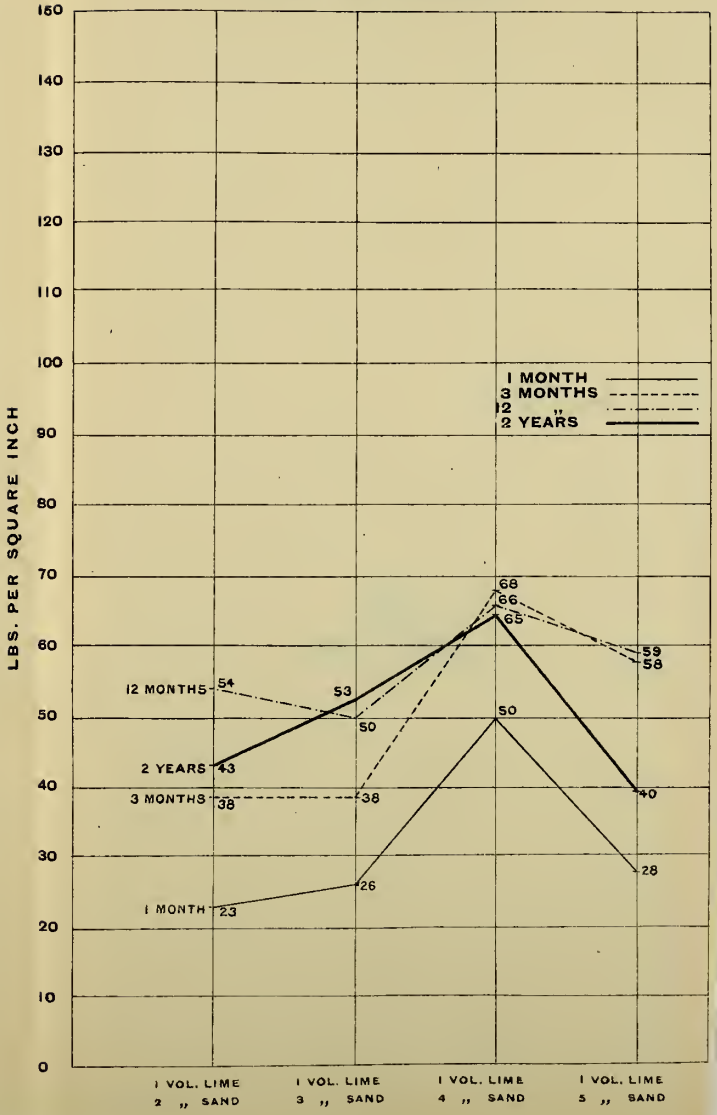
LONDON AND BUNGAY

TABLE XIII.

DIAGRAM SERIES A.a.

TENSILE STRENGTH.

WHITE CHALK LIME.
+STANDARD SAND.



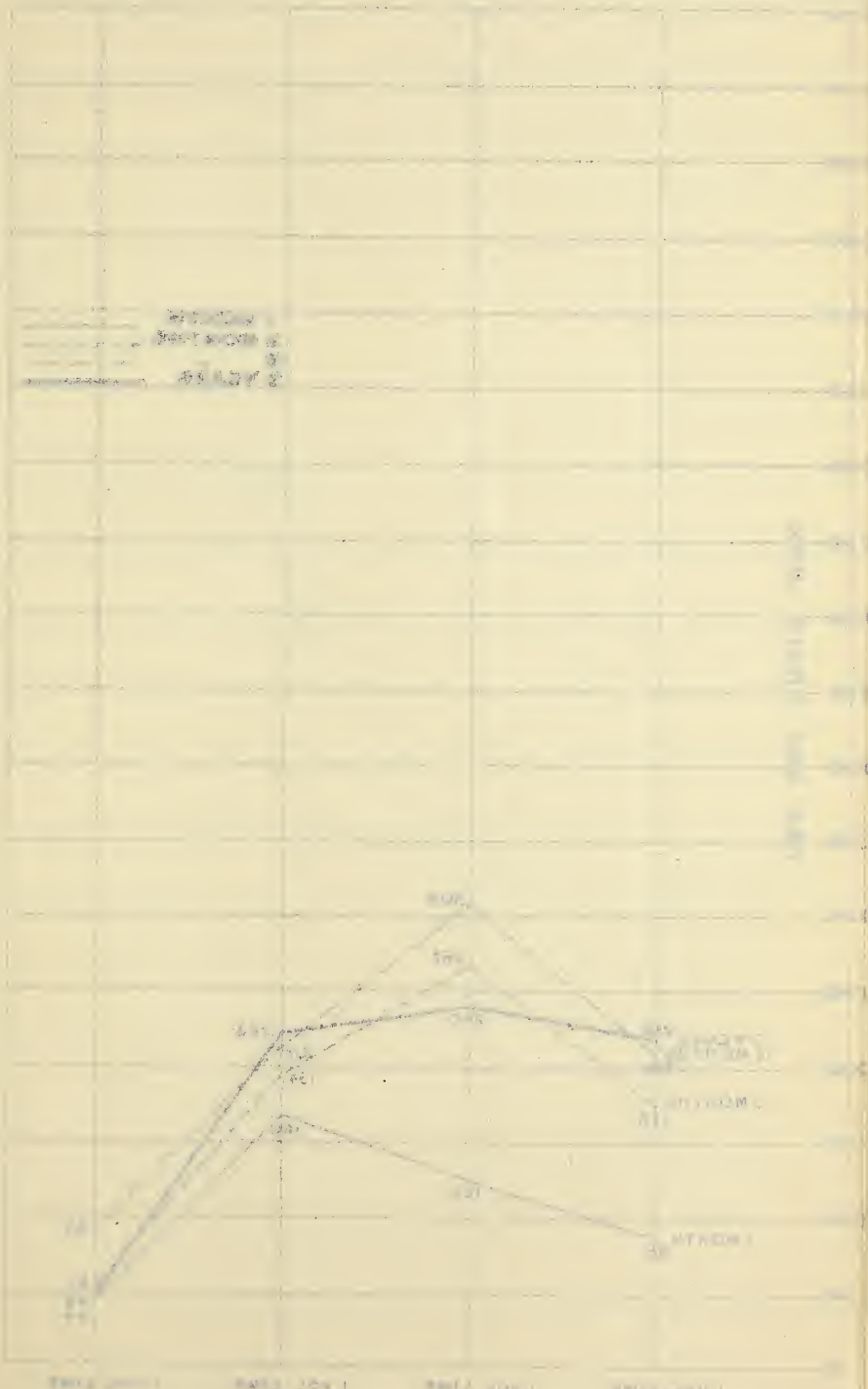
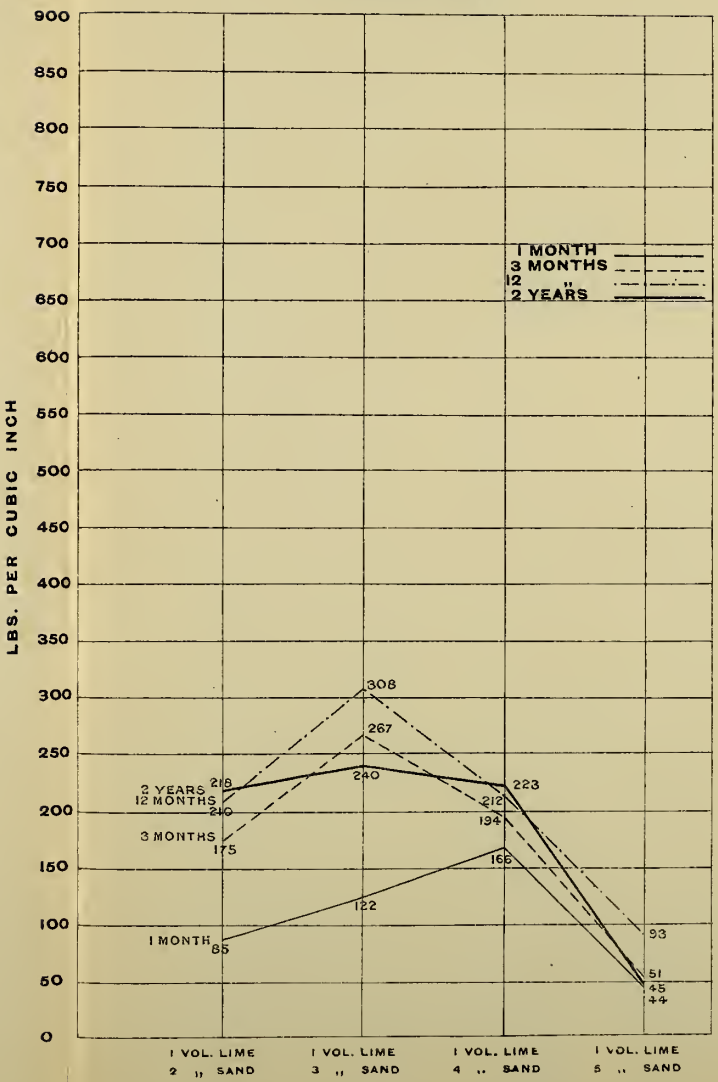


TABLE XIII.

DIAGRAM SERIES Aa!

CRUSHING STRENGTH.

WHITE CHALK LIME.
+STANDARD SAND.



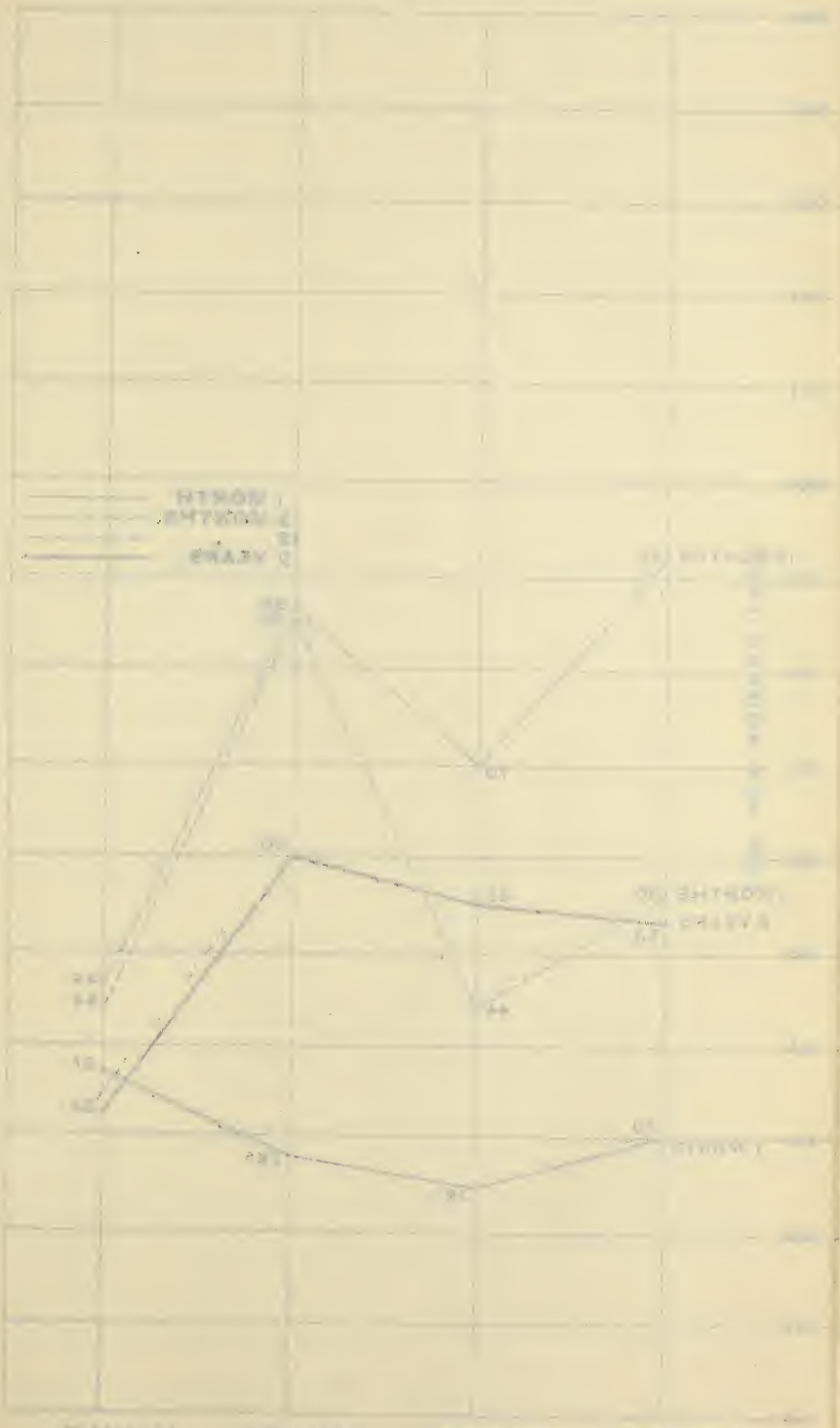
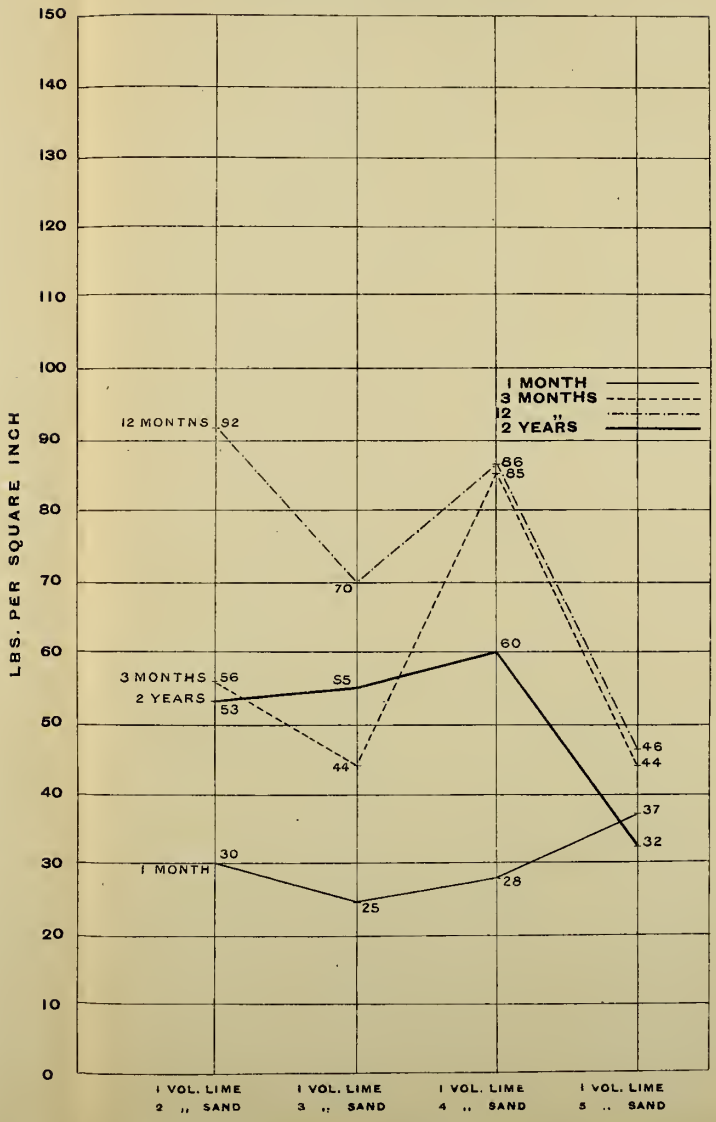


TABLE XIII.

DIAGRAM SERIES A.b.

TENSILE STRENGTH.

WHITE CHALK LIME.
+FINE SAND CHARLTON)



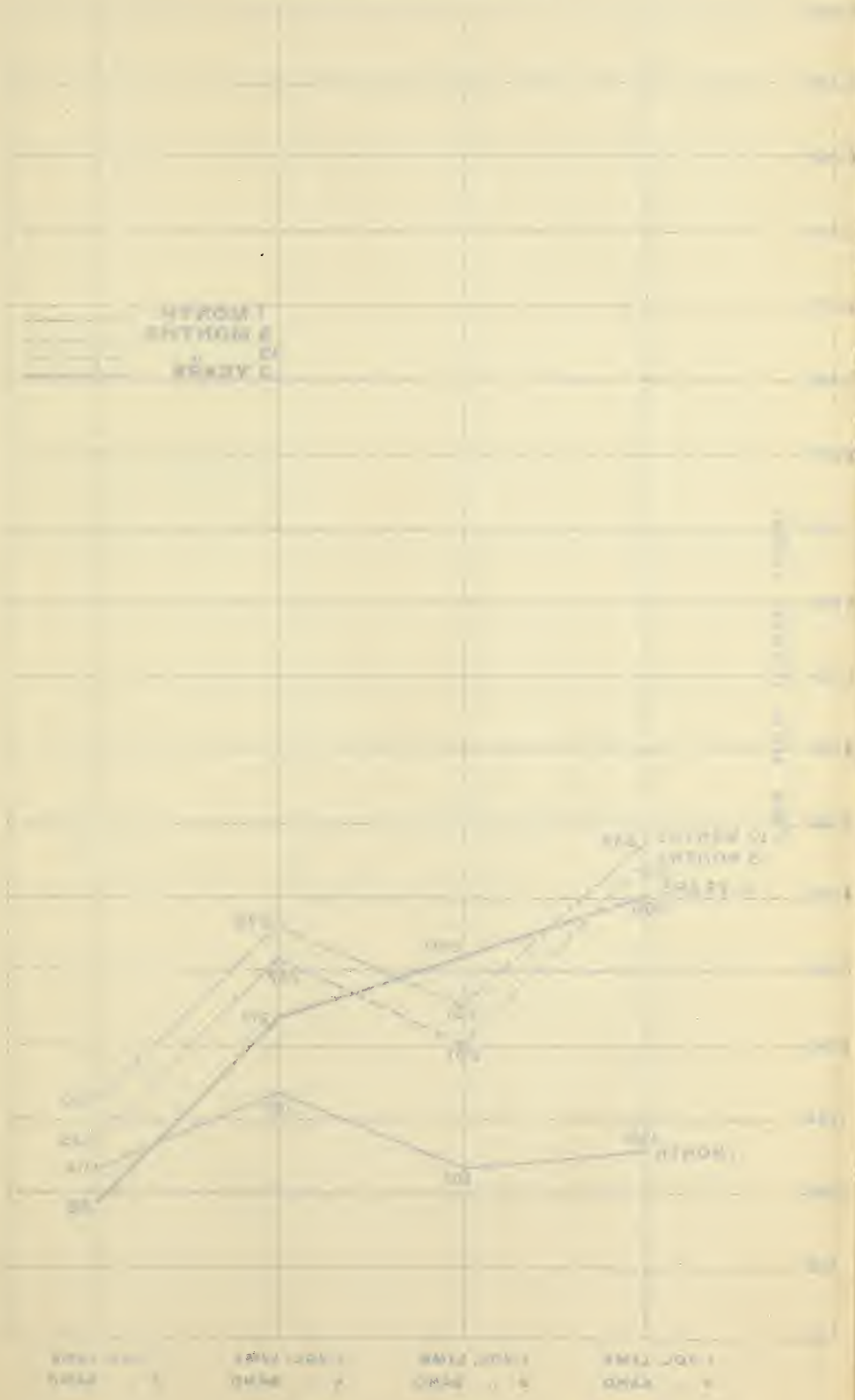
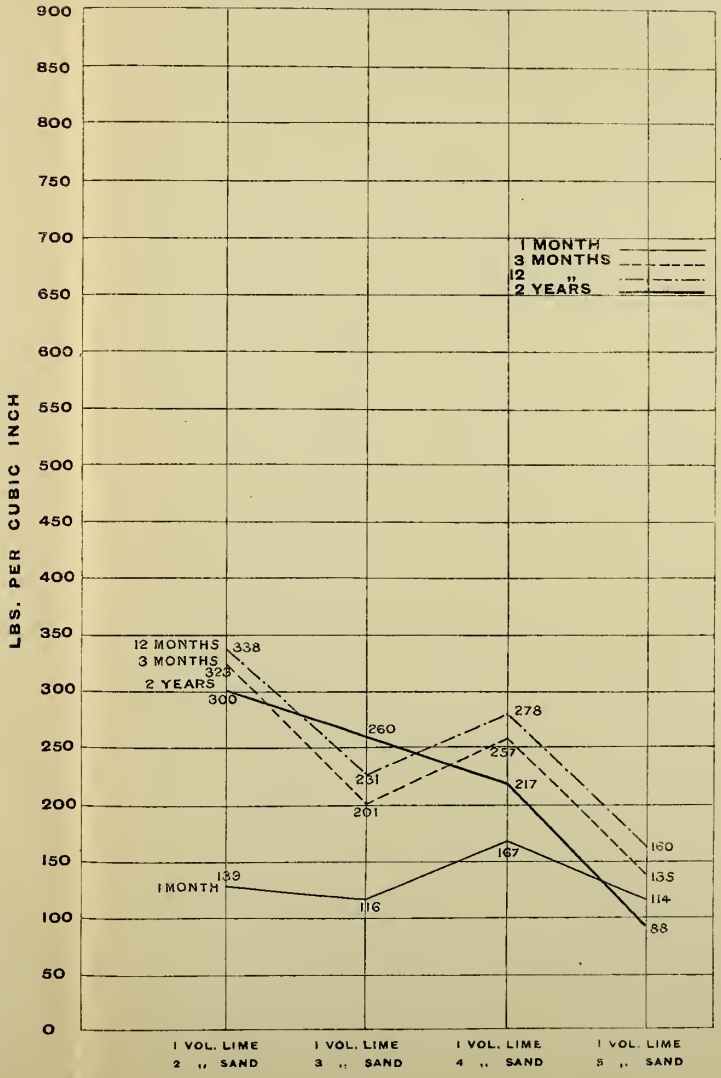


TABLE XIII.

DIAGRAM SERIES A6!

CRUSHING STRENGTH.

WHITE CHALK LIME.
+FINE SAND (CHARLTON)



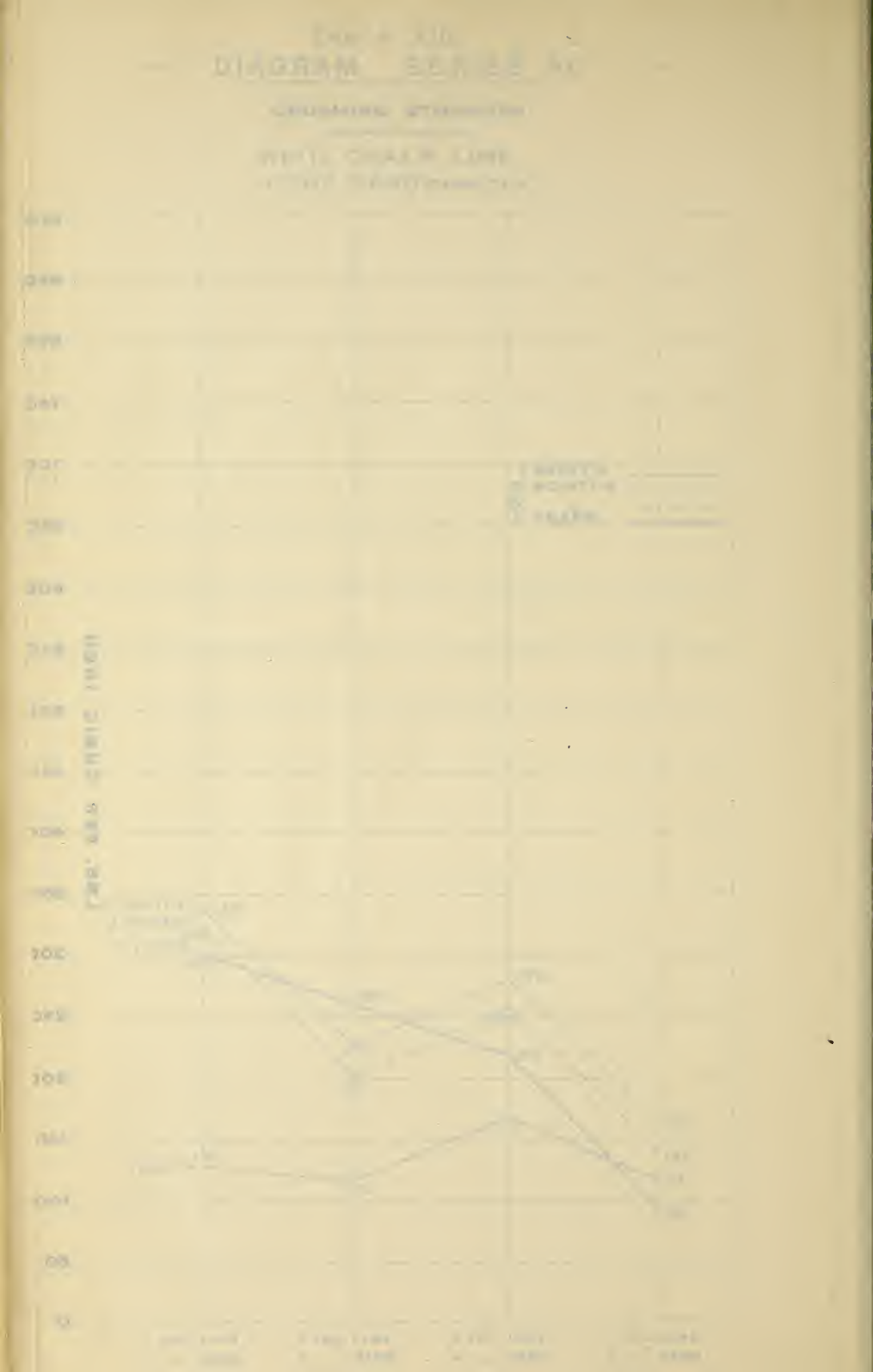
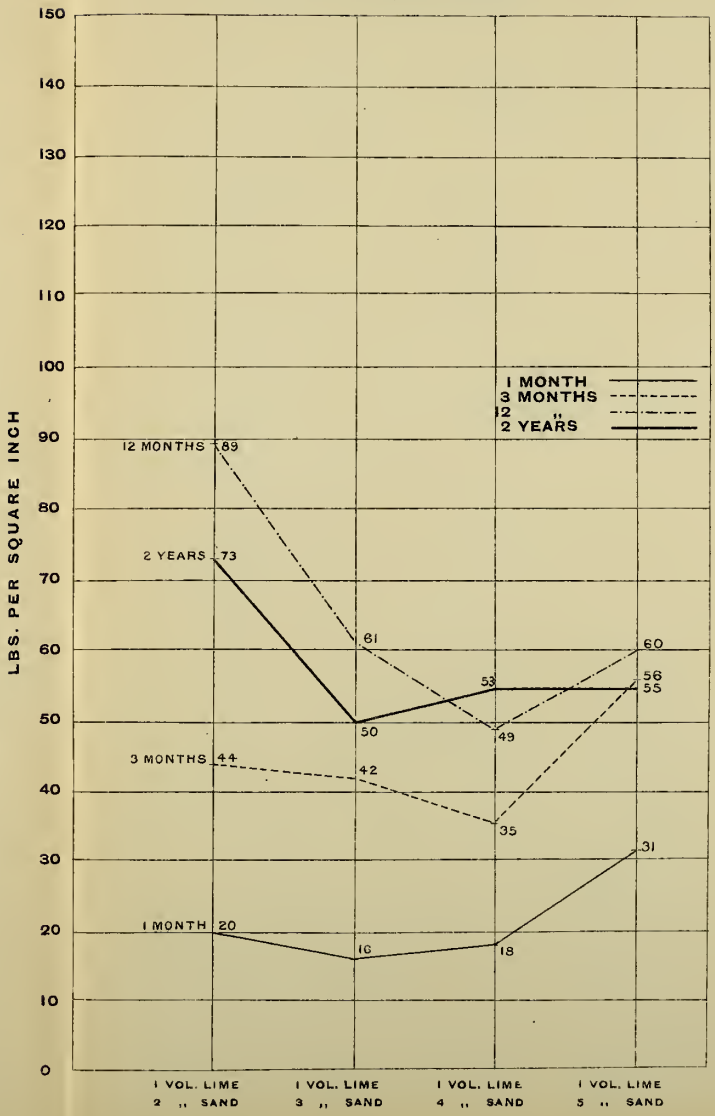


TABLE XIII.

DIAGRAM SERIES A C.

TENSILE STRENGTH.

WHITE CHALK LIME.
+ PIT SAND (ORDINARY)



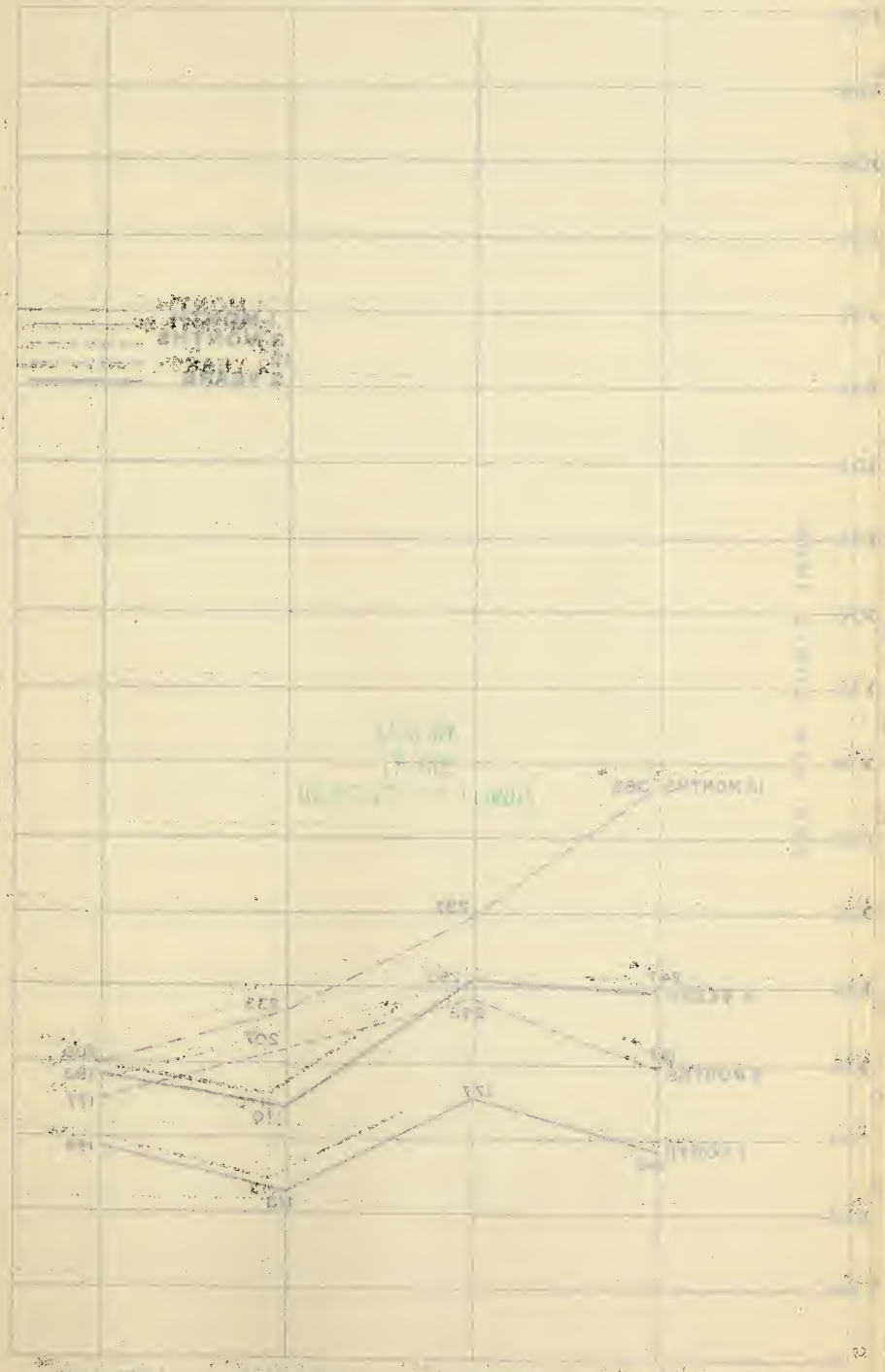
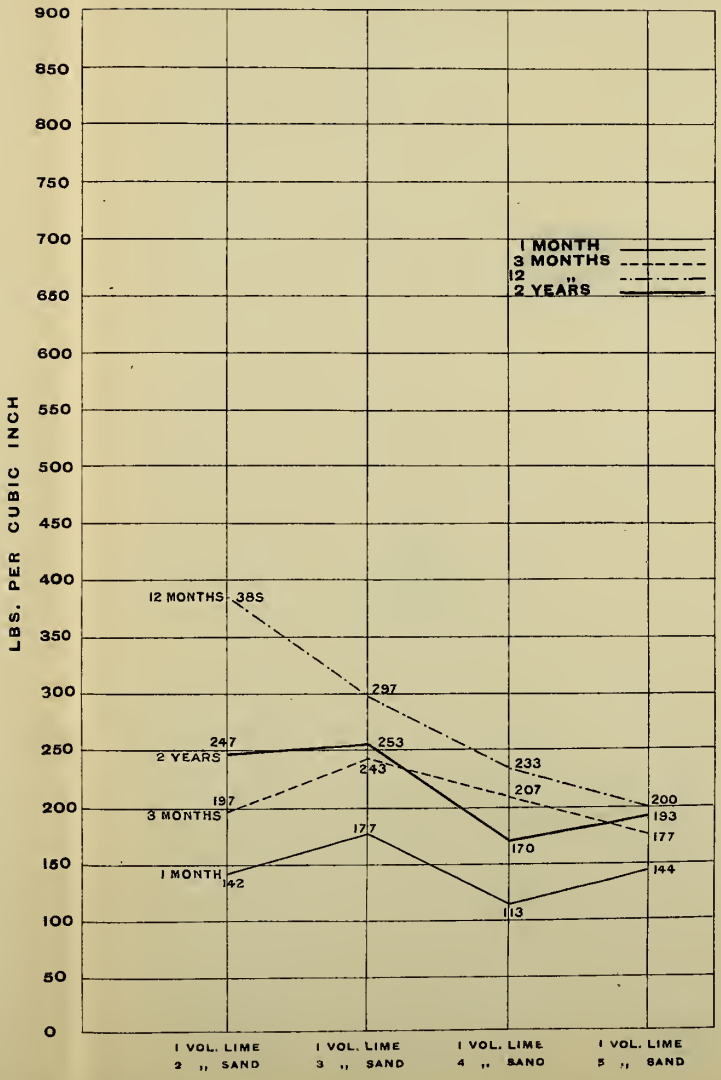


TABLE XIII.

DIAGRAM SERIES Ac!

CRUSHING STRENGTH.

WHITE CHALK LIME.
+ PIT SAND. (ORDINARY)



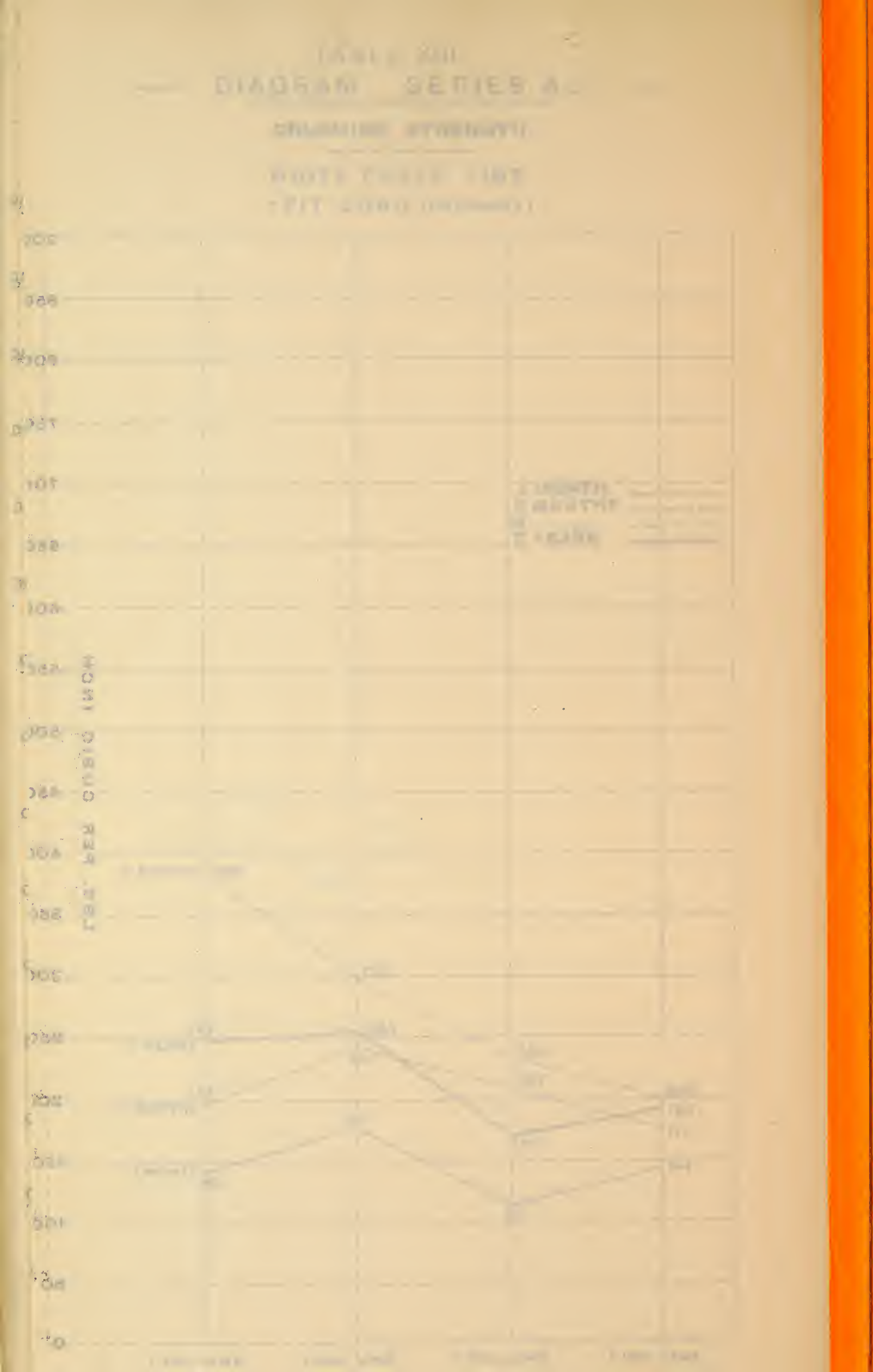
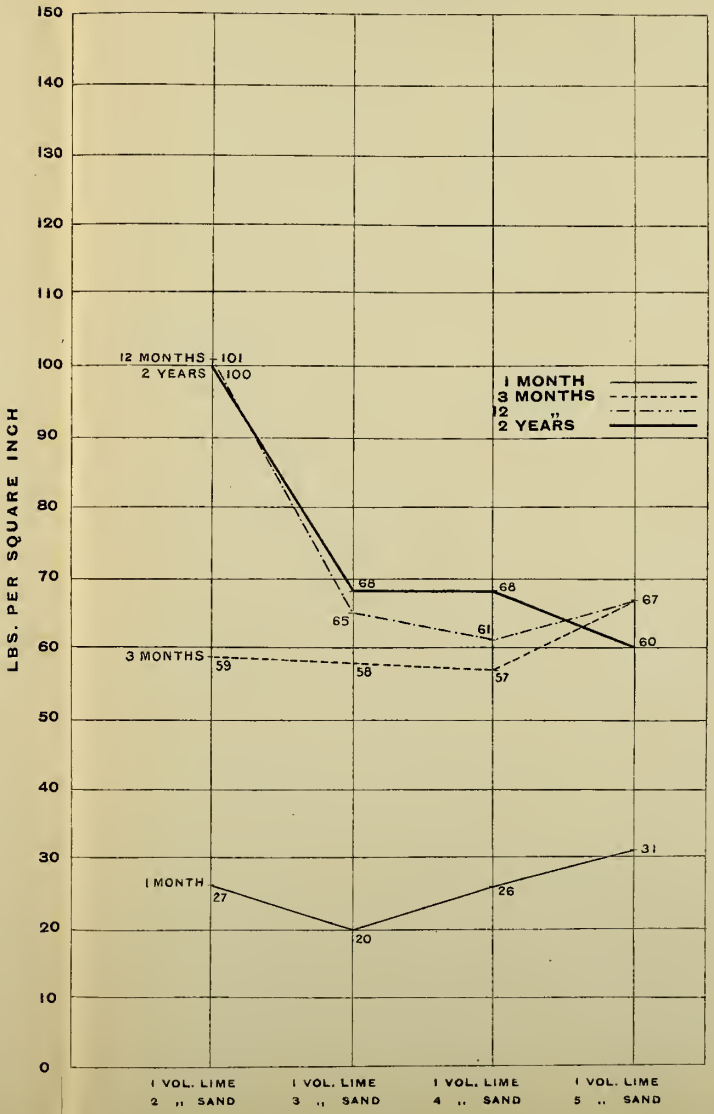


TABLE XIII.

DIAGRAM SERIES Ad.

TENSILE STRENGTH.

WHITE CHALK LIME.
+THAMES SAND



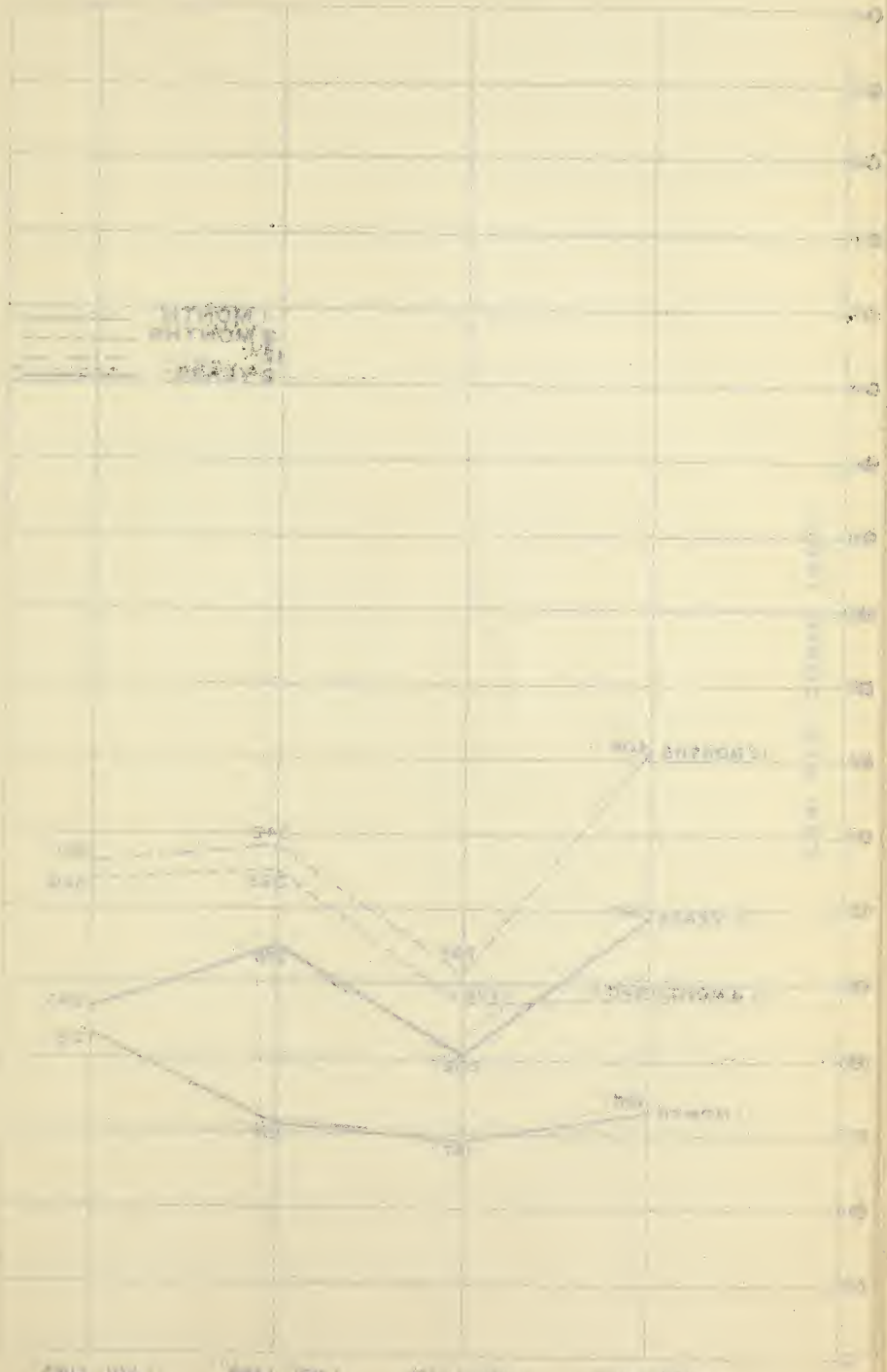


TABLE XIII.

DIAGRAM SERIES Ad!

CRUSHING STRENGTH.

WHITE CHALK LIME.
+ THAMES SAND.

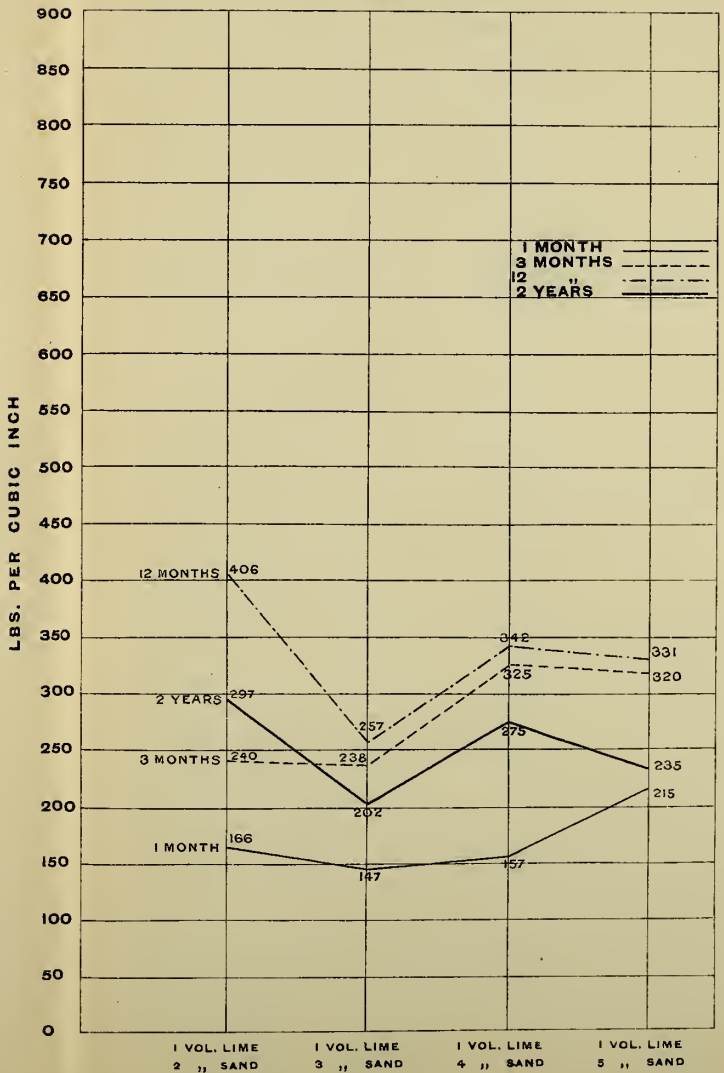


TABLE XIII

DIAGRAM SERIES A.1

CRUSHING STRENGTH.

WHITE CHALK LIME

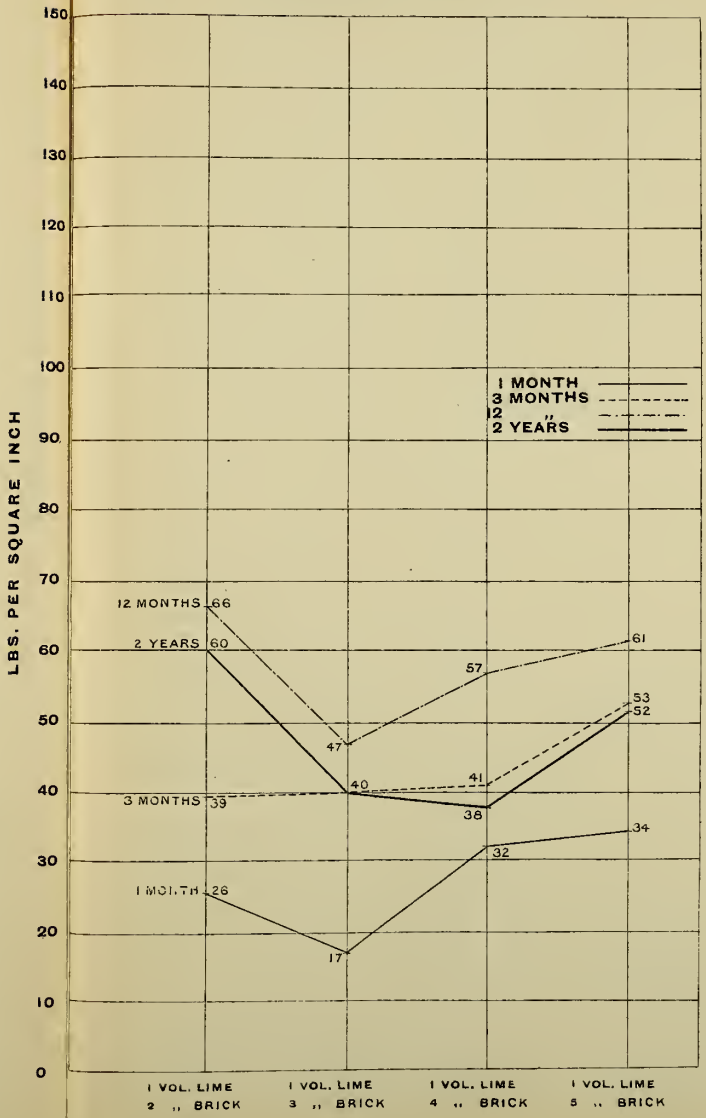
FRAMES LAND

TABLE XIII.

DIAGRAM SERIES Ae

TENSILE STRENGTH.

WHITE CHALK LIME.
+ GROUND BRICK.



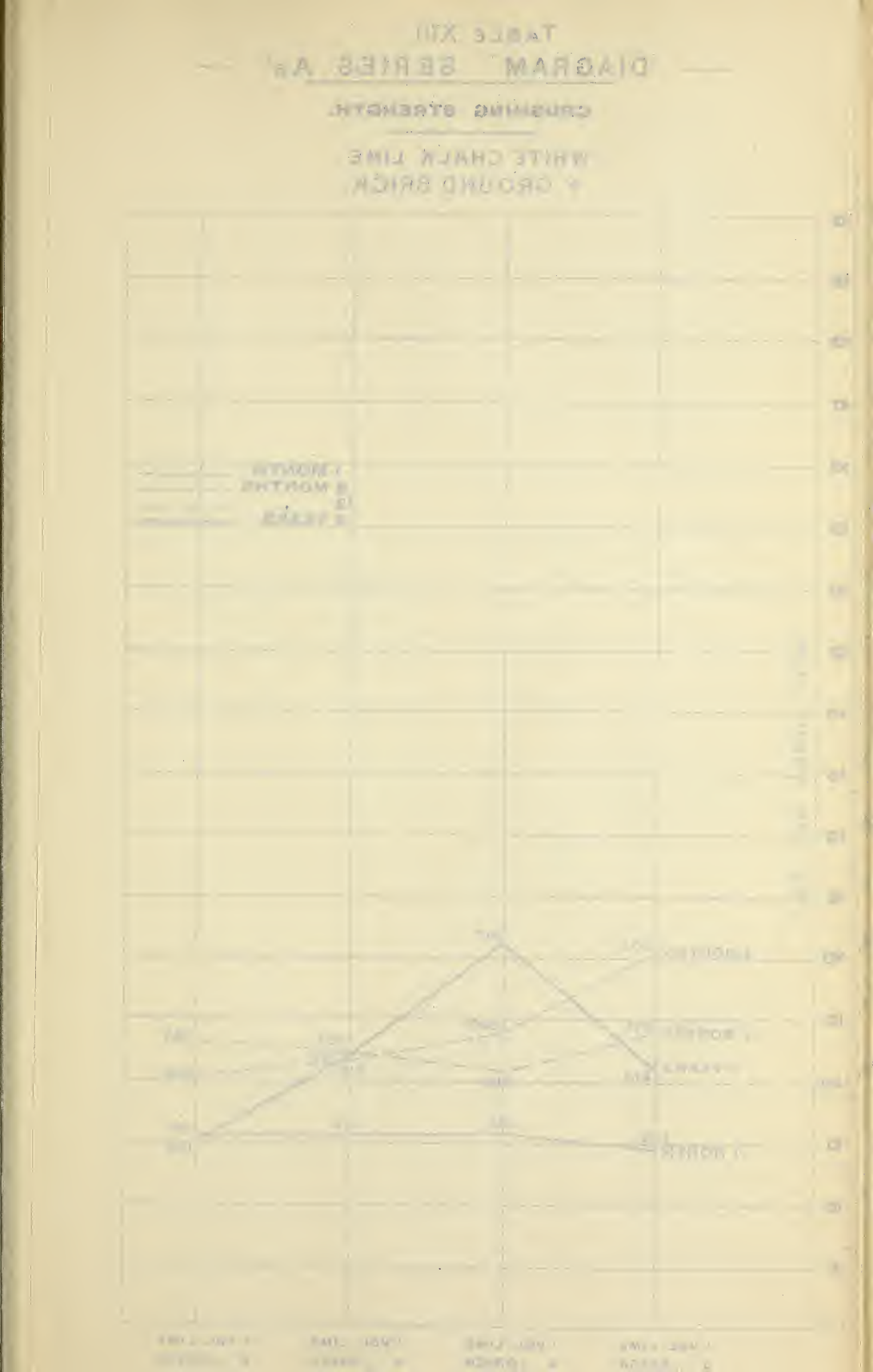


TABLE [illegible]

VIAGRAM SERIES [illegible]

TENSILE STRENGTH

WHITE CHALK LIME

[illegible] BRICK

TABLE XIII.

DIAGRAM SERIES Ae!

CRUSHING STRENGTH.

WHITE CHALK LIME.
+ GROUND BRICK.

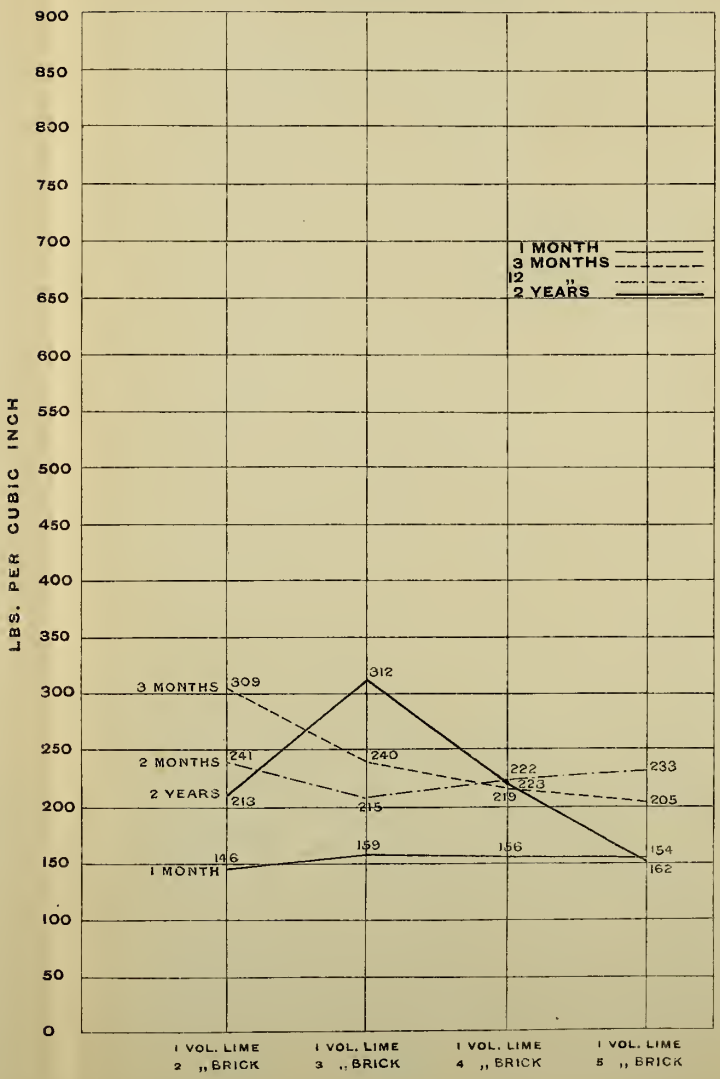
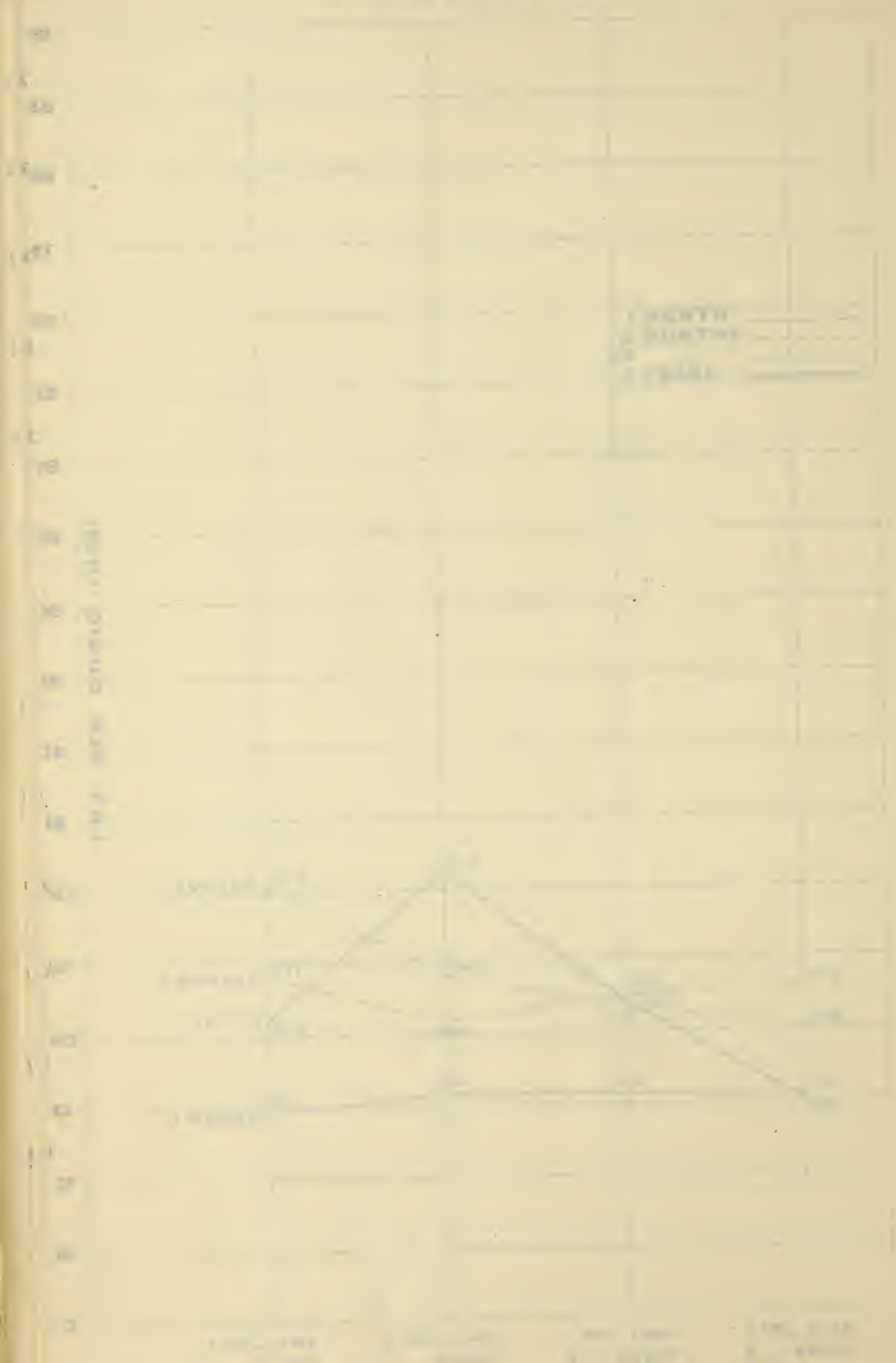


TABLE XIV

DIAGRAM SERIES A-A

CRUSHING STRENGTH

WHITE CHALK LIME
+ GROUND BRICK



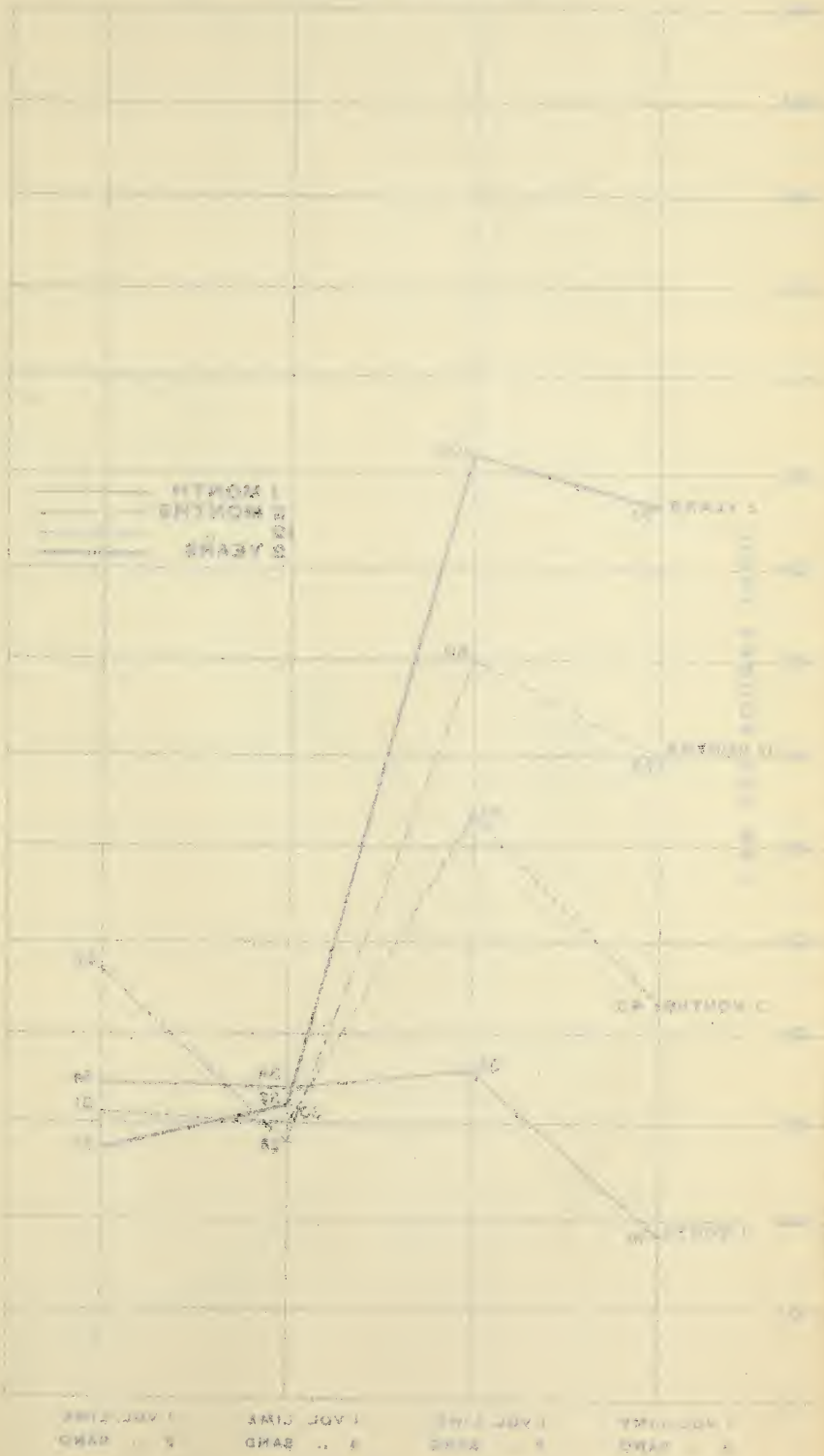


TABLE XIII

DIAGRAM. SERIES A-1

CRUSHING STRENGTH.

WHITE CABLE LINE
- SECOND BRICK.

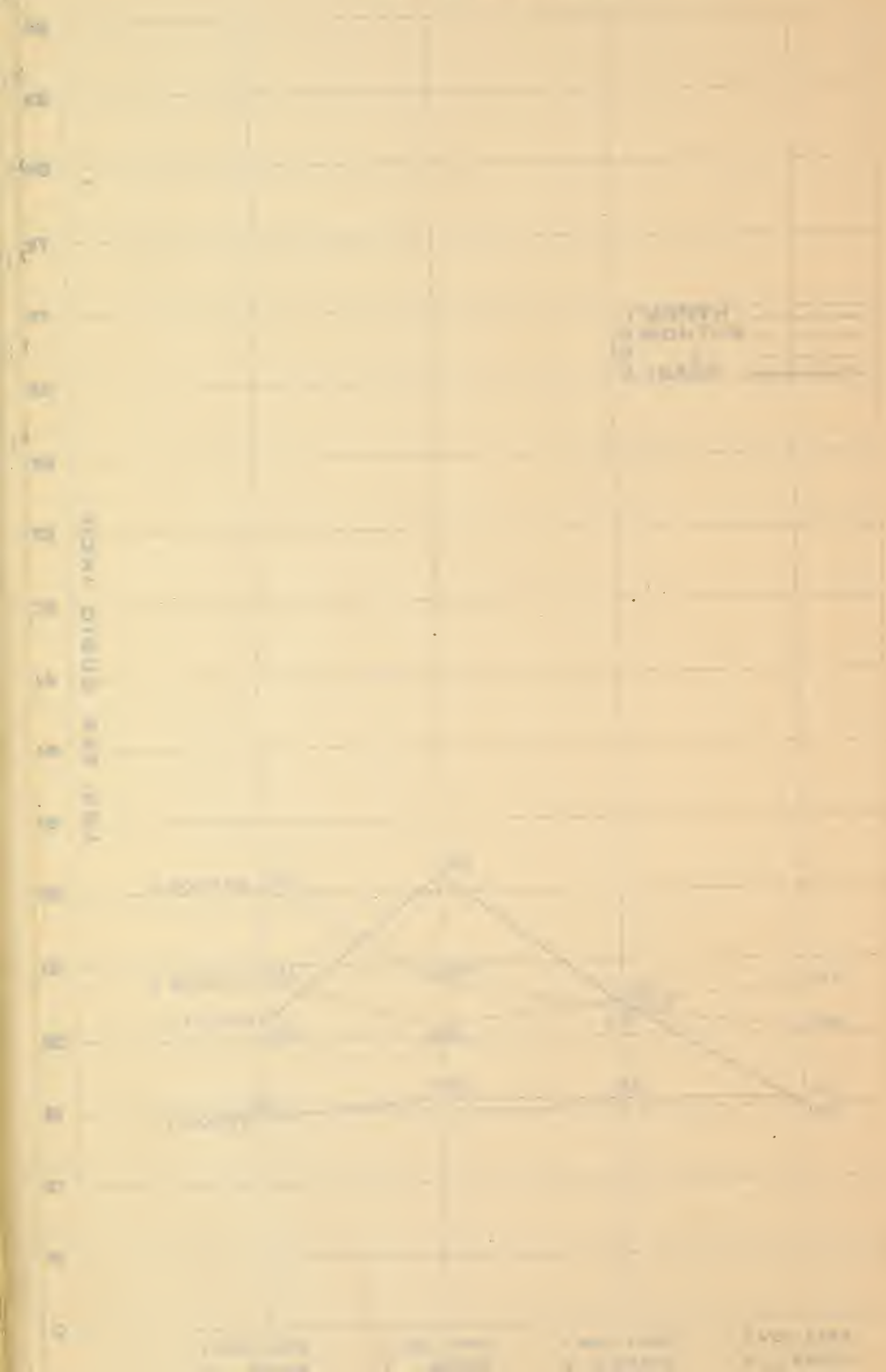
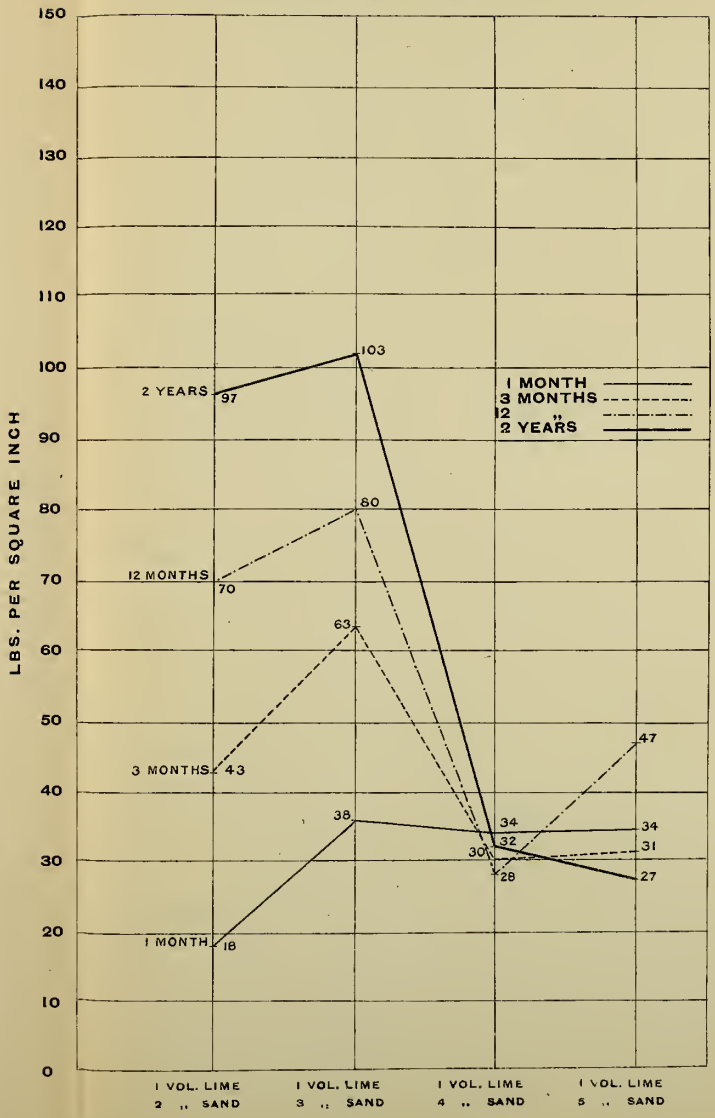


TABLE XIV.

DIAGRAM SERIES B.a.

TENSILE STRENGTH.

DORKING GREY STONE LIME.
+STANDARD SAND.



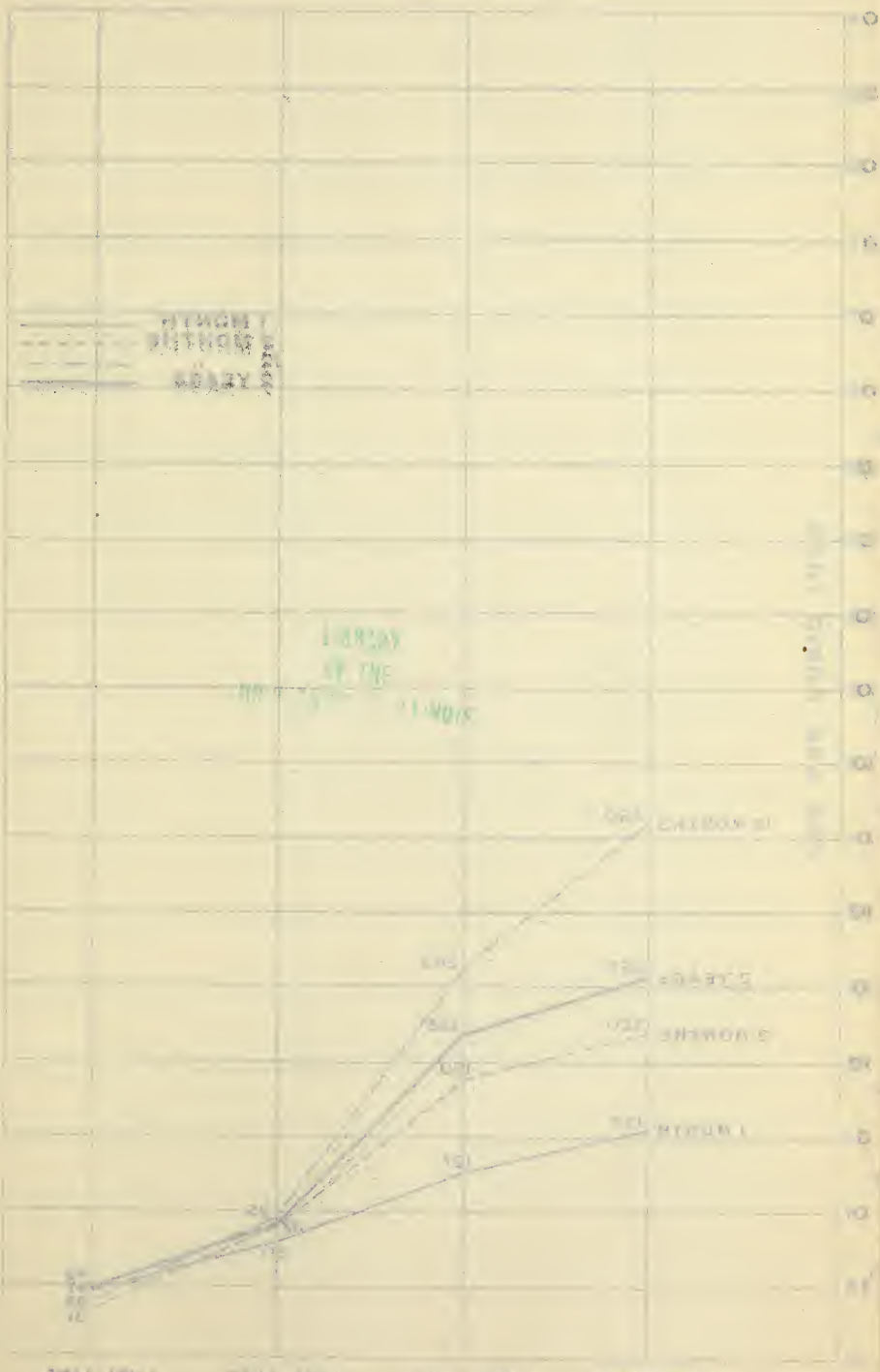
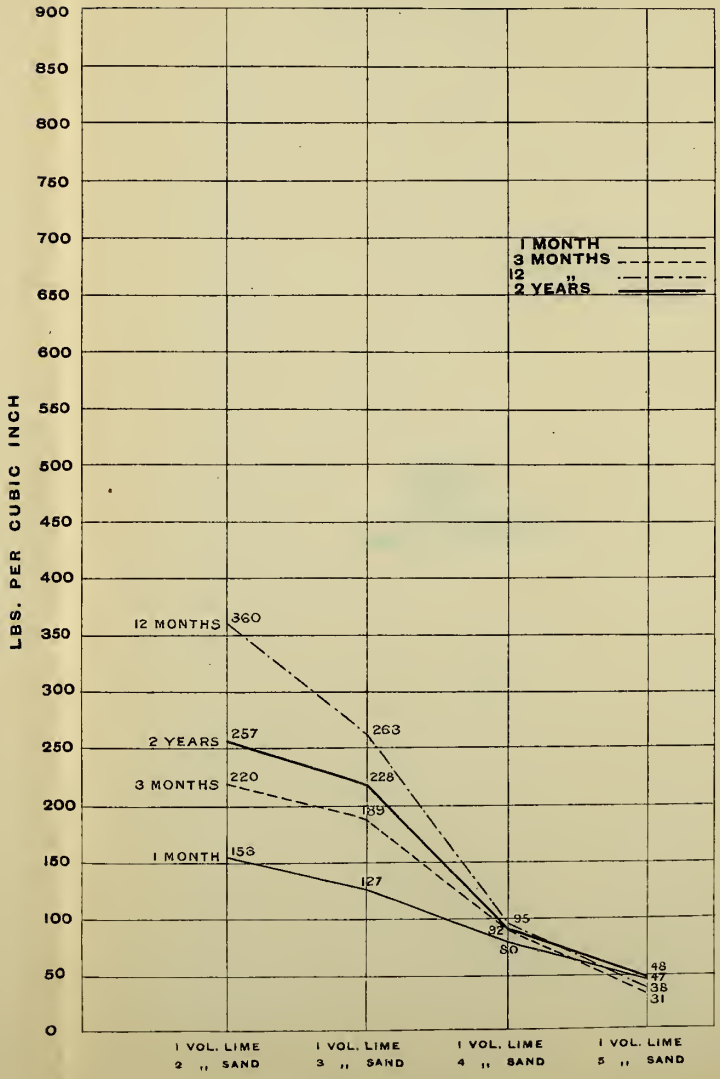


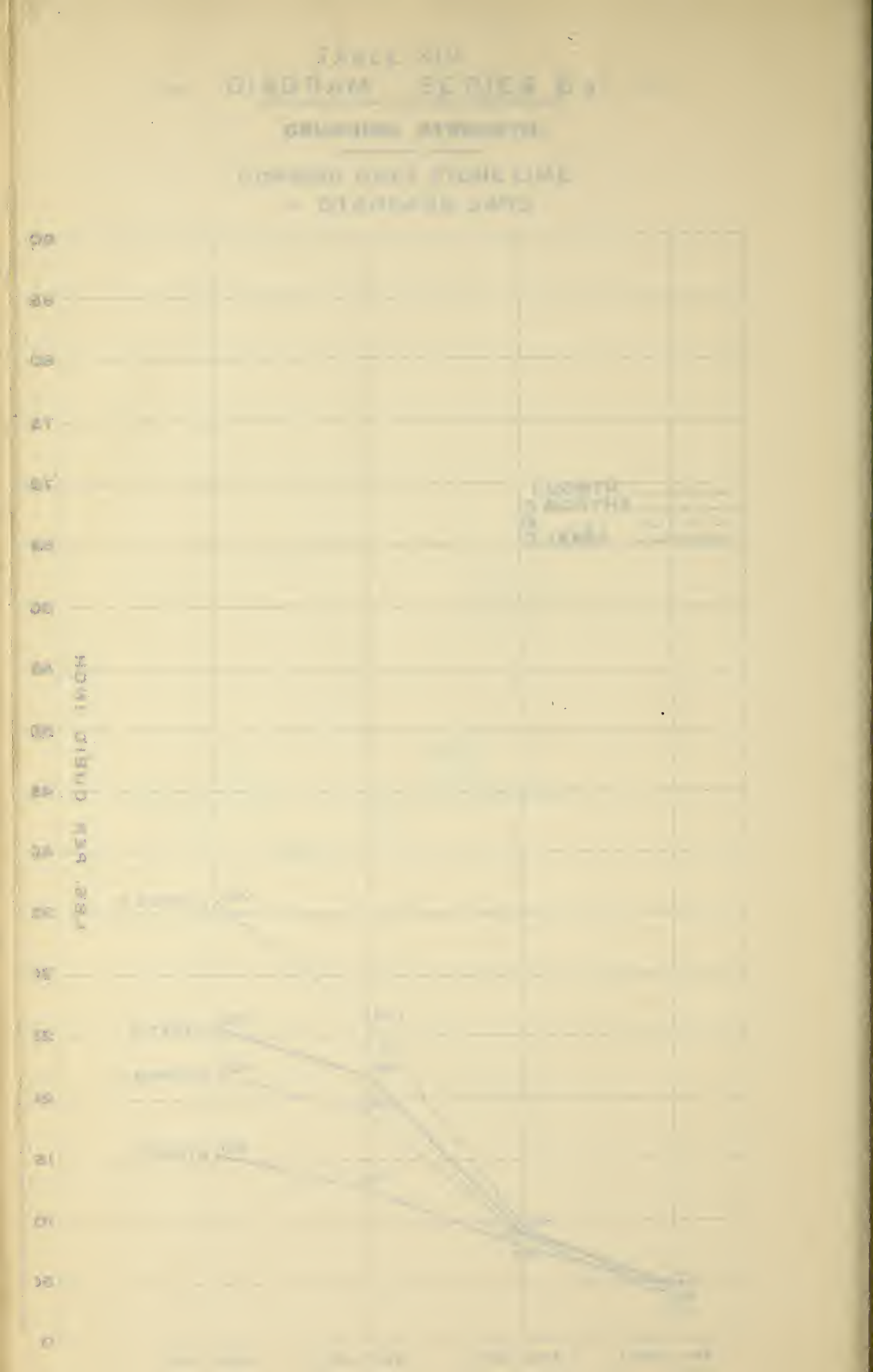
TABLE XIV.

DIAGRAM SERIES Ba!

CRUSHING STRENGTH.

DORKING GREY STONE LIME
+ STANDARD SAND





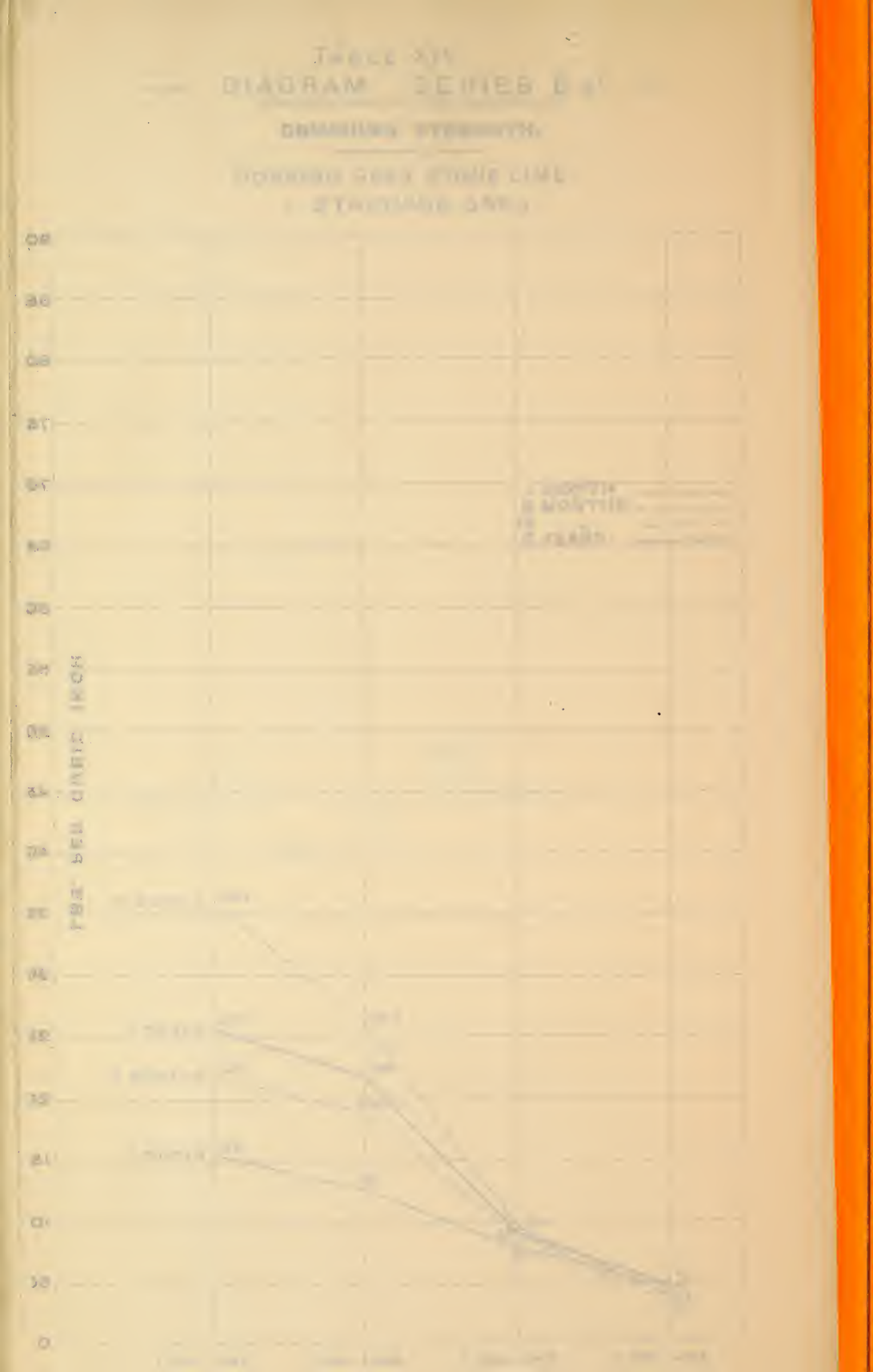


TABLE XIV.

DIAGRAM SERIES B.b.

TENSILE STRENGTH.

DORKING GREY STONE LIME.
+ FINE SAND (CHARLTON)

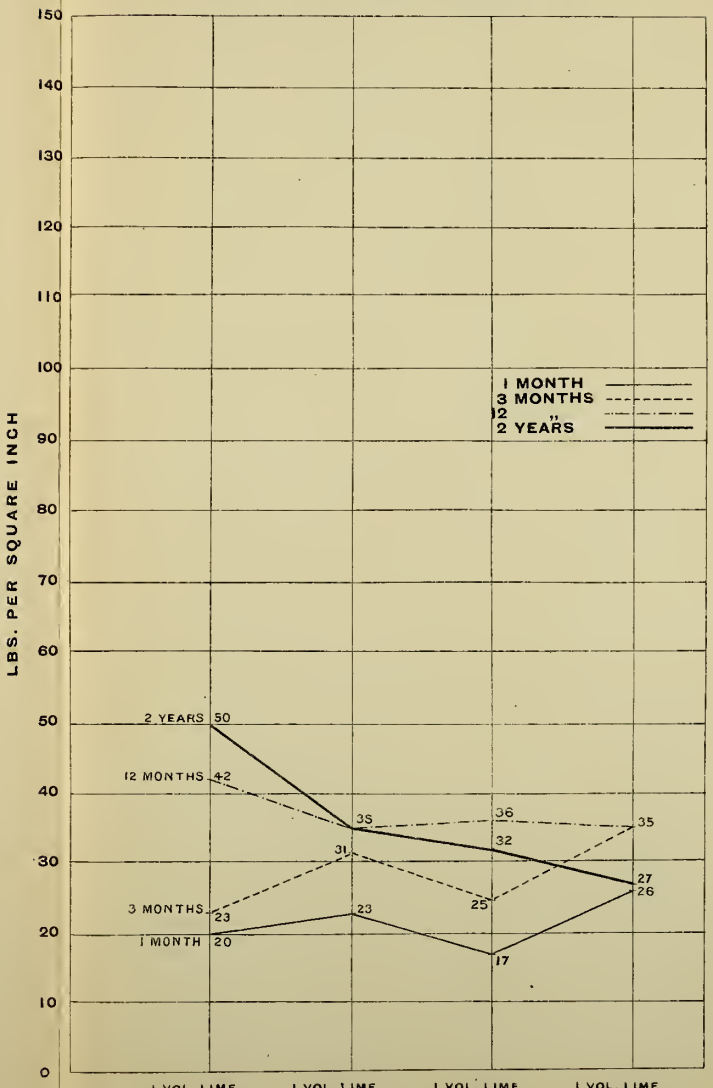
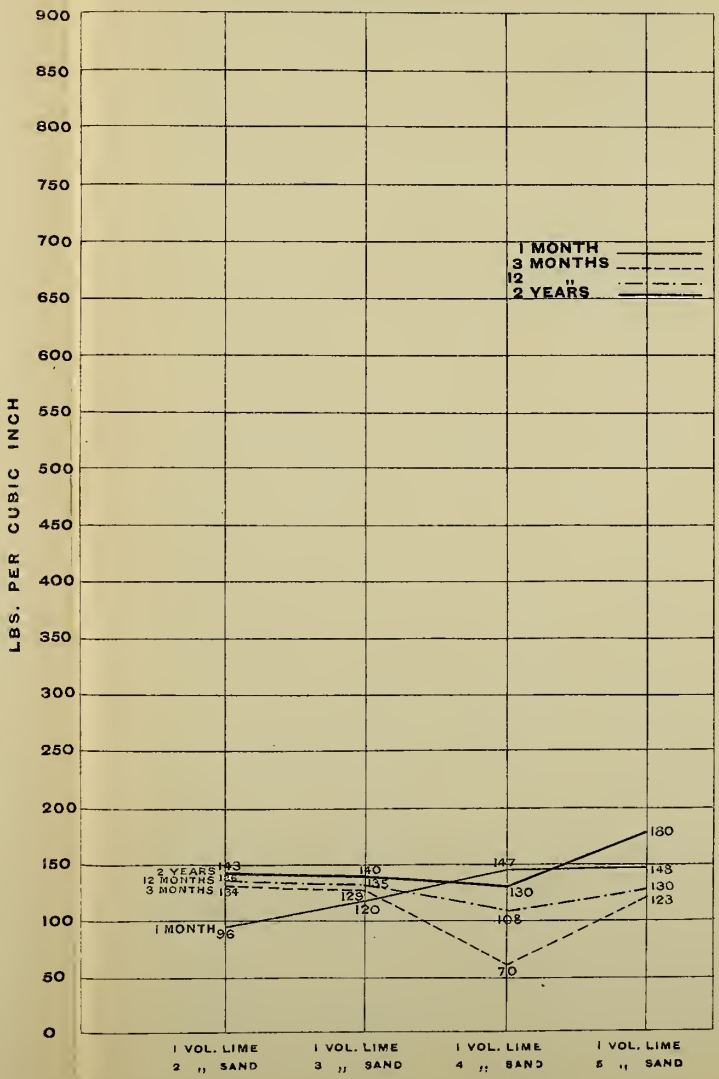


TABLE XIV.

DIAGRAM SERIES Bb!

CRUSHING STRENGTH.

DORKING GREY STONE LIME
+ FINE SAND (CHARLTON)



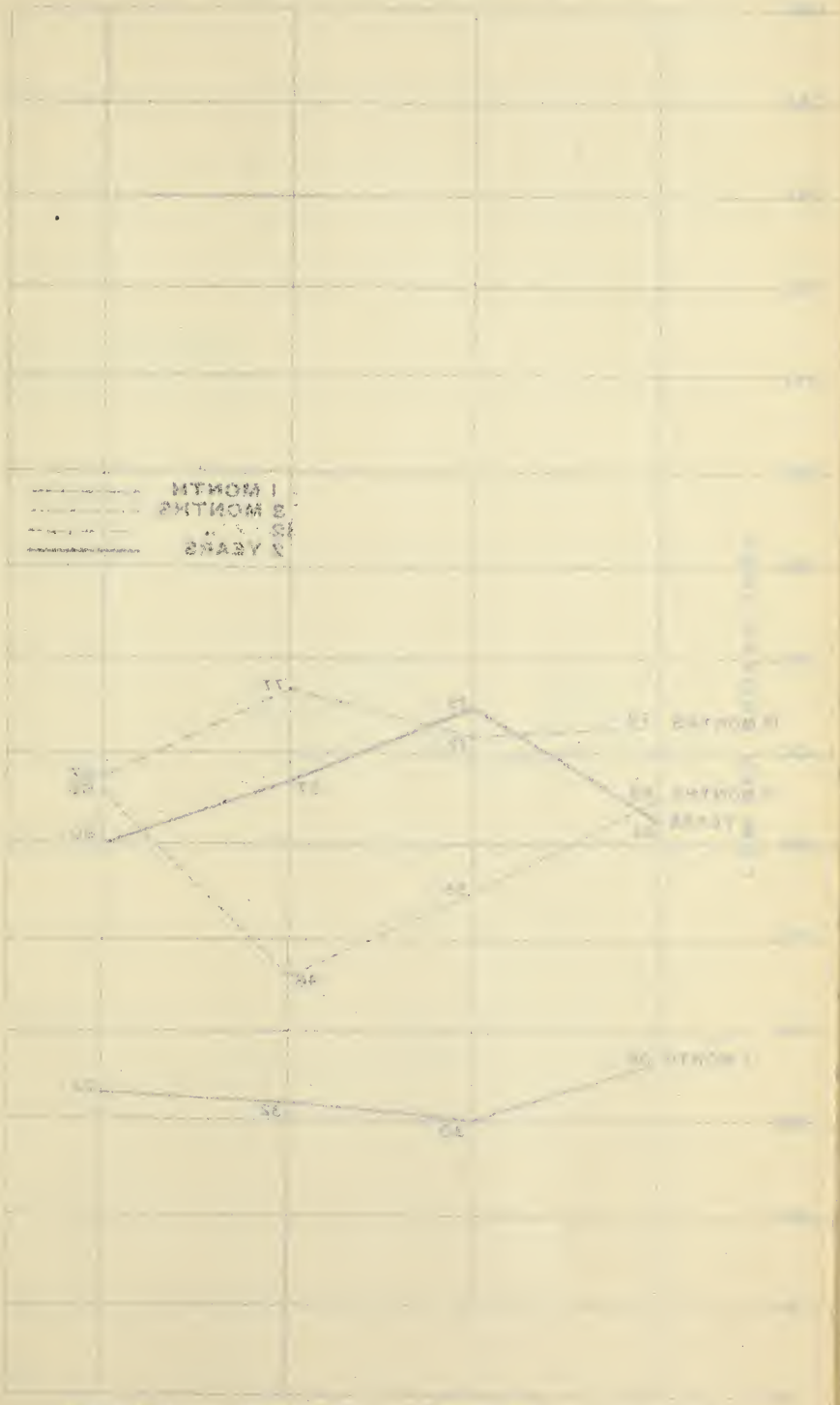


TABLE XIV.

DIAGRAM SERIES B.c.

TENSILE STRENGTH.

DORKING GREY STONE LIME.
+PIT SAND (ORDINARY)

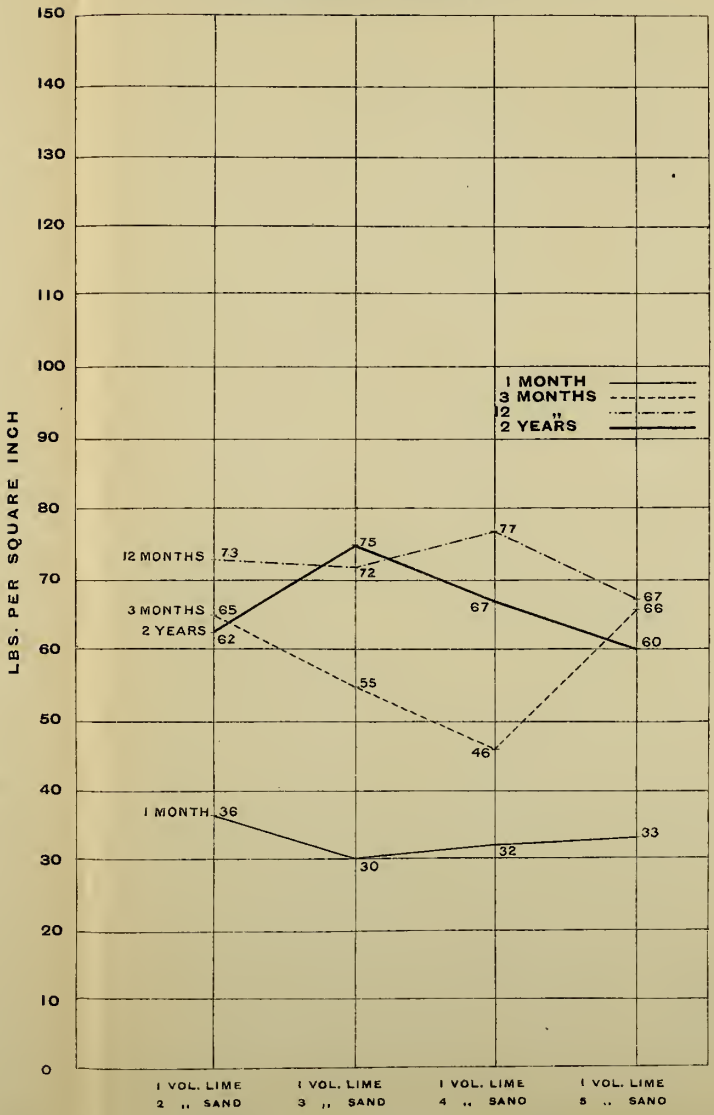
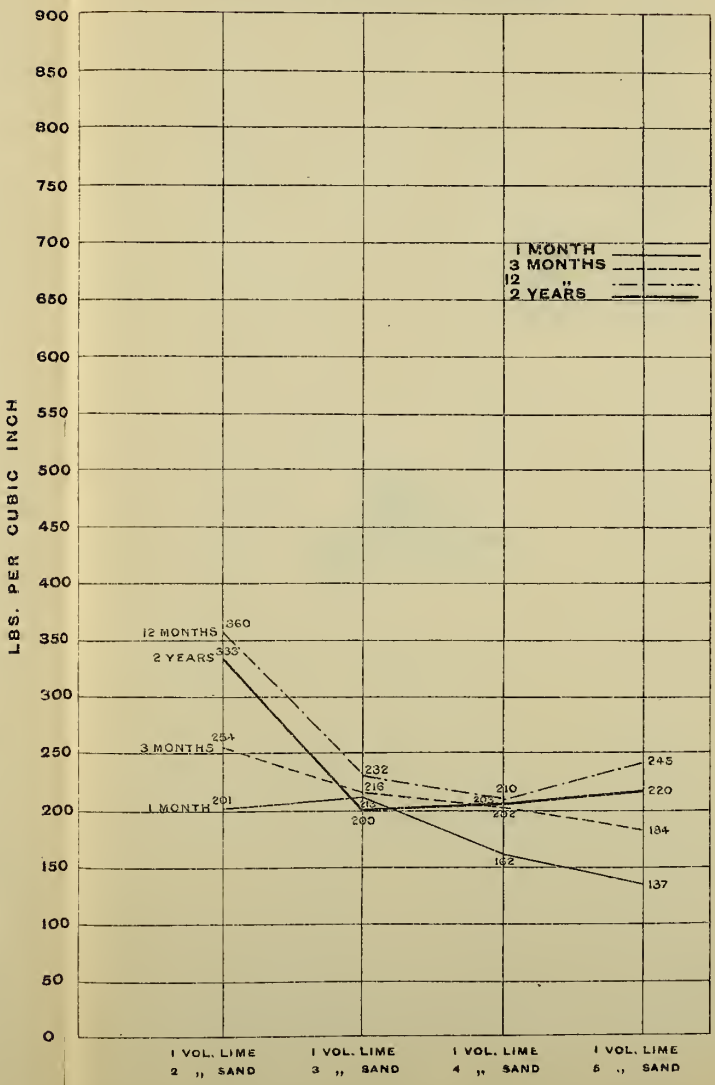


TABLE XIV.

DIAGRAM SERIES Bc!

CRUSHING STRENGTH.

DORKING GREY STONE LIME.
+PIT SAND (ORDINARY)



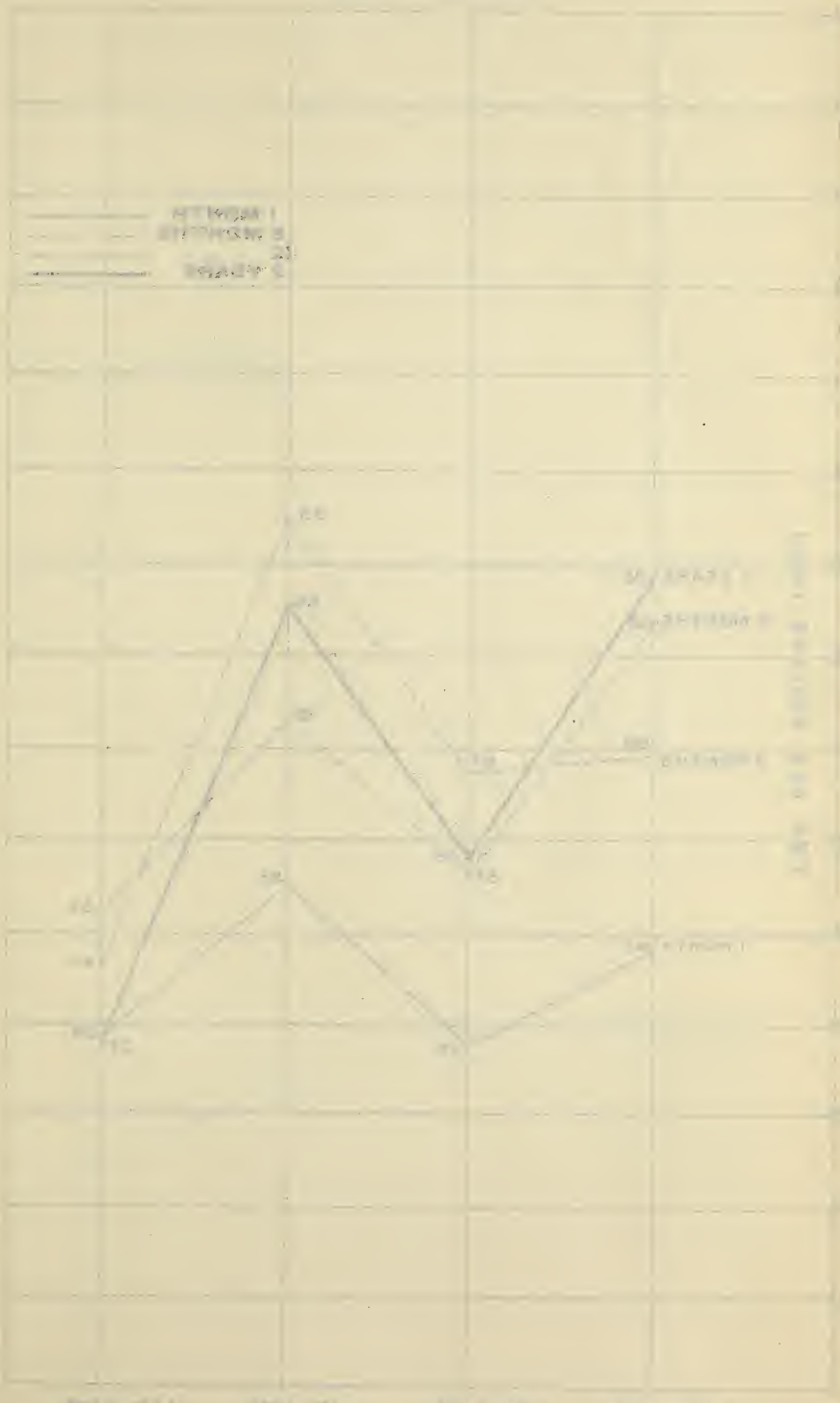
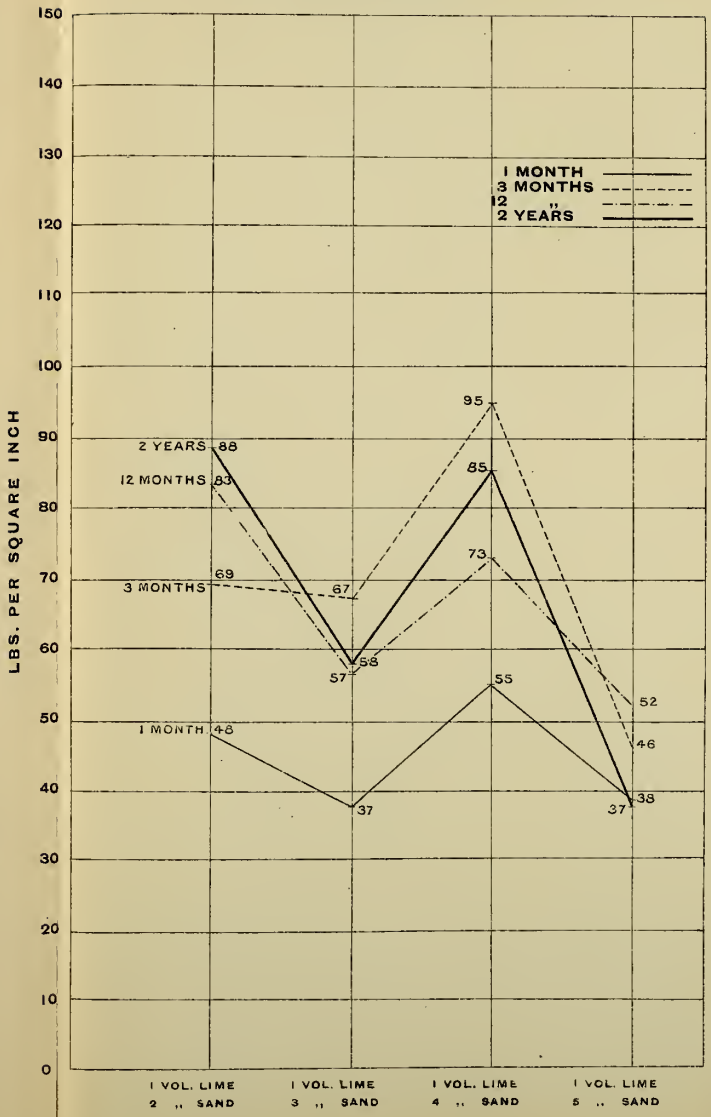


TABLE XIV.

DIAGRAM SERIES B.d.

TENSILE STRENGTH.

DORKING GREY STONE LIME
+ THAMES SAND



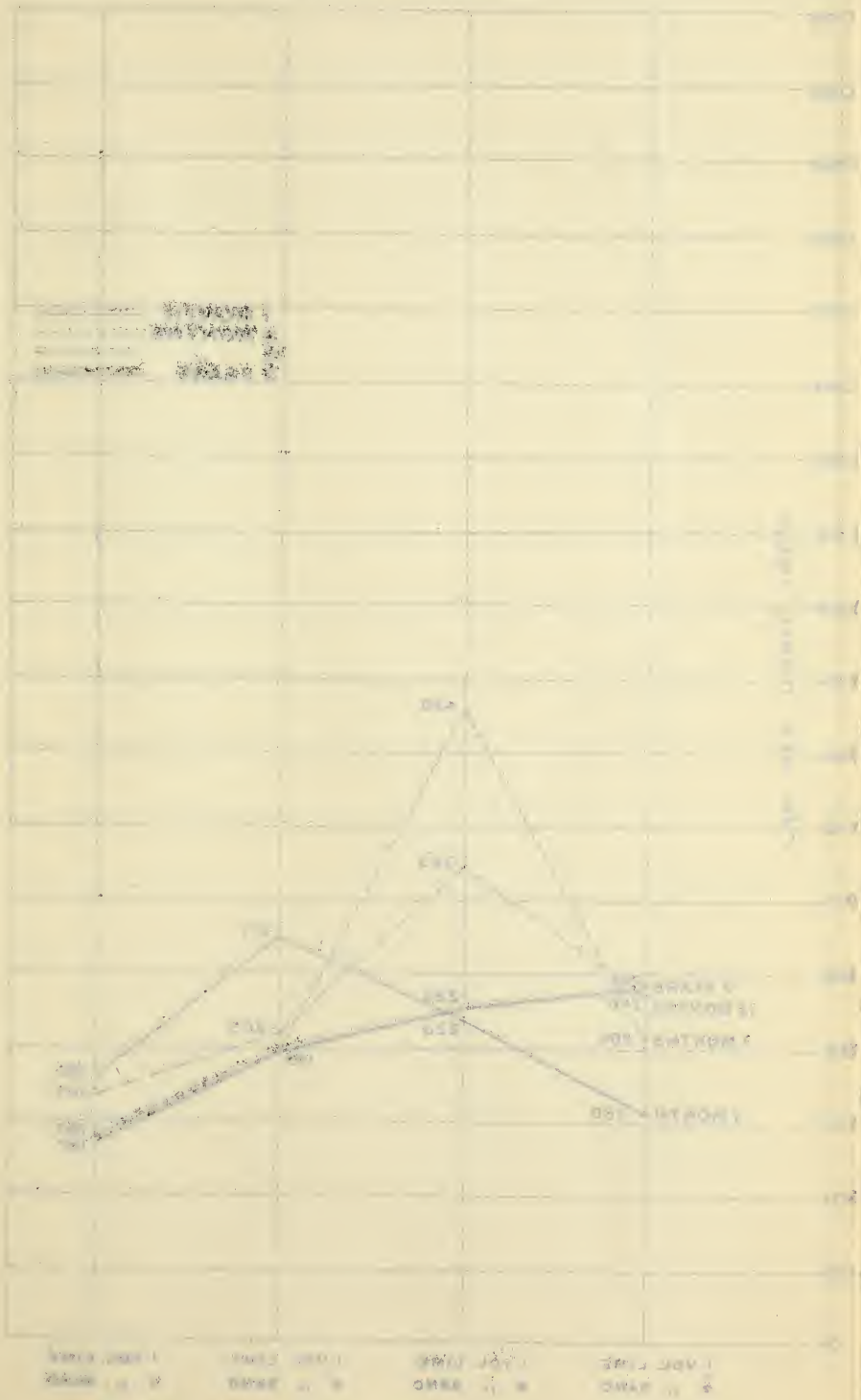
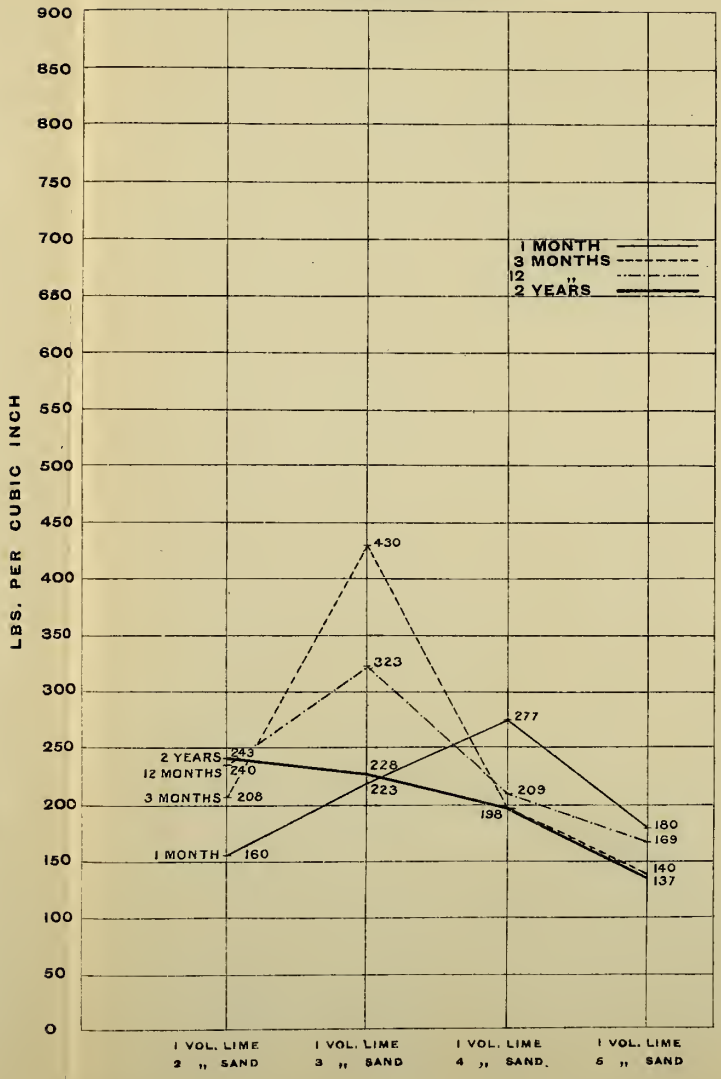


TABLE XIV.

DIAGRAM SERIES B.d!

CRUSHING STRENGTH.

DORKING GREY STONE LIME
+THAMES SAND.



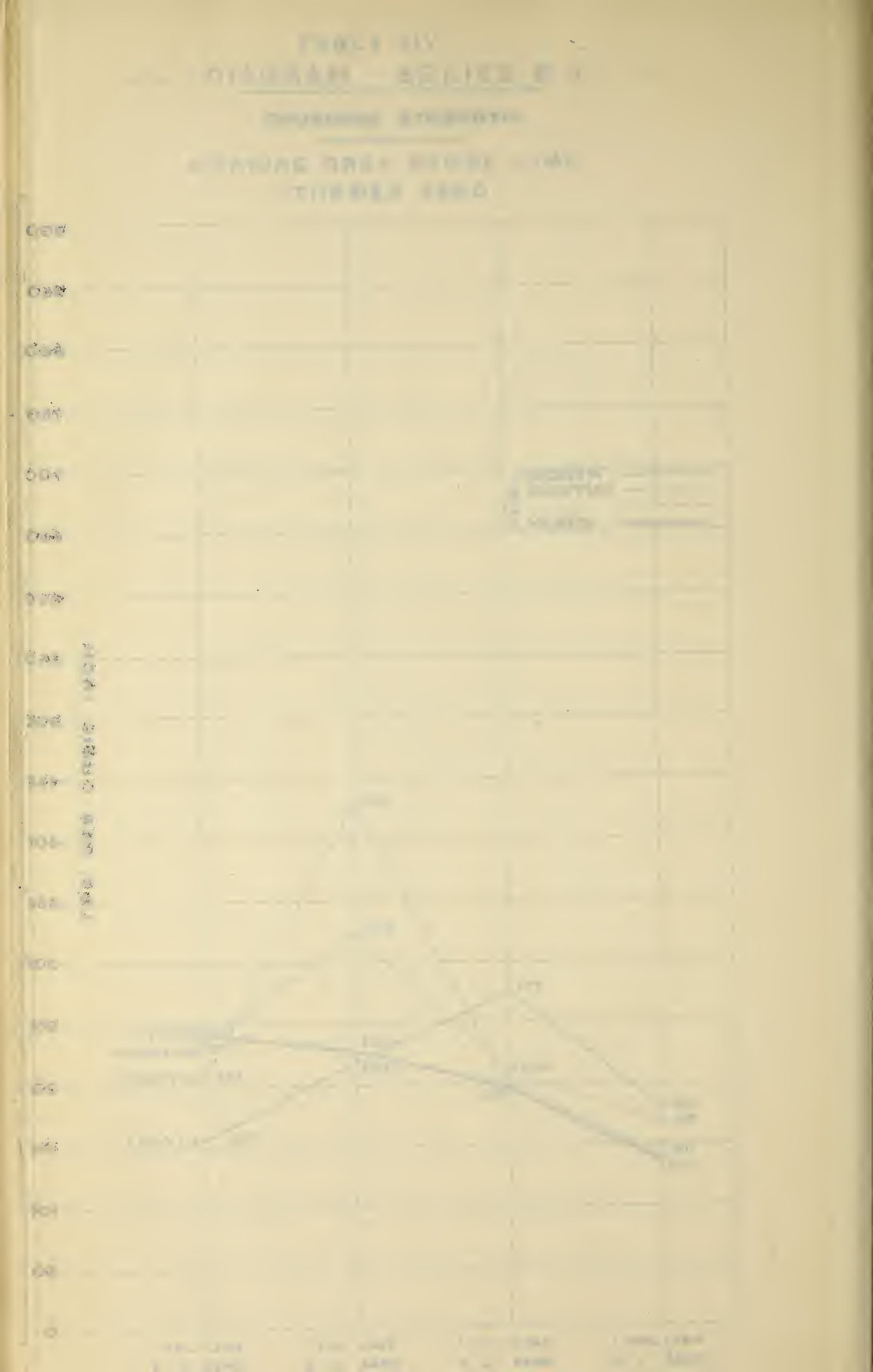
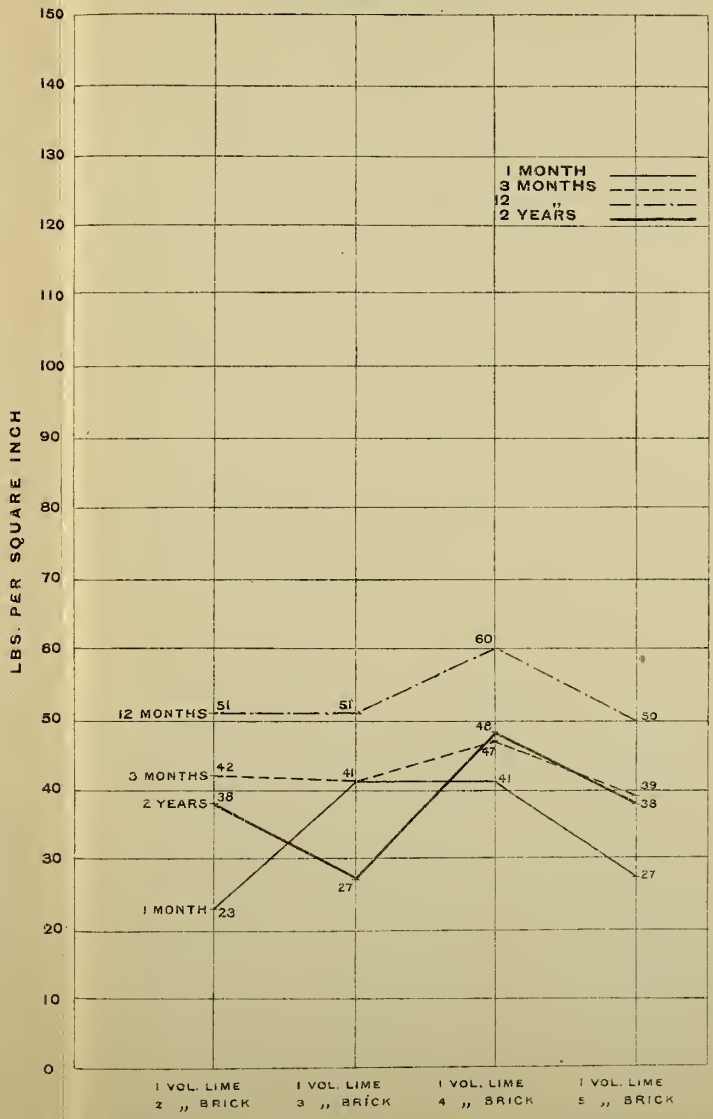


TABLE XIV.

DIAGRAM SERIES B.e.

TENSILE STRENGTH.

DORKING GREY STONE LIME
+ GROUND BRICK



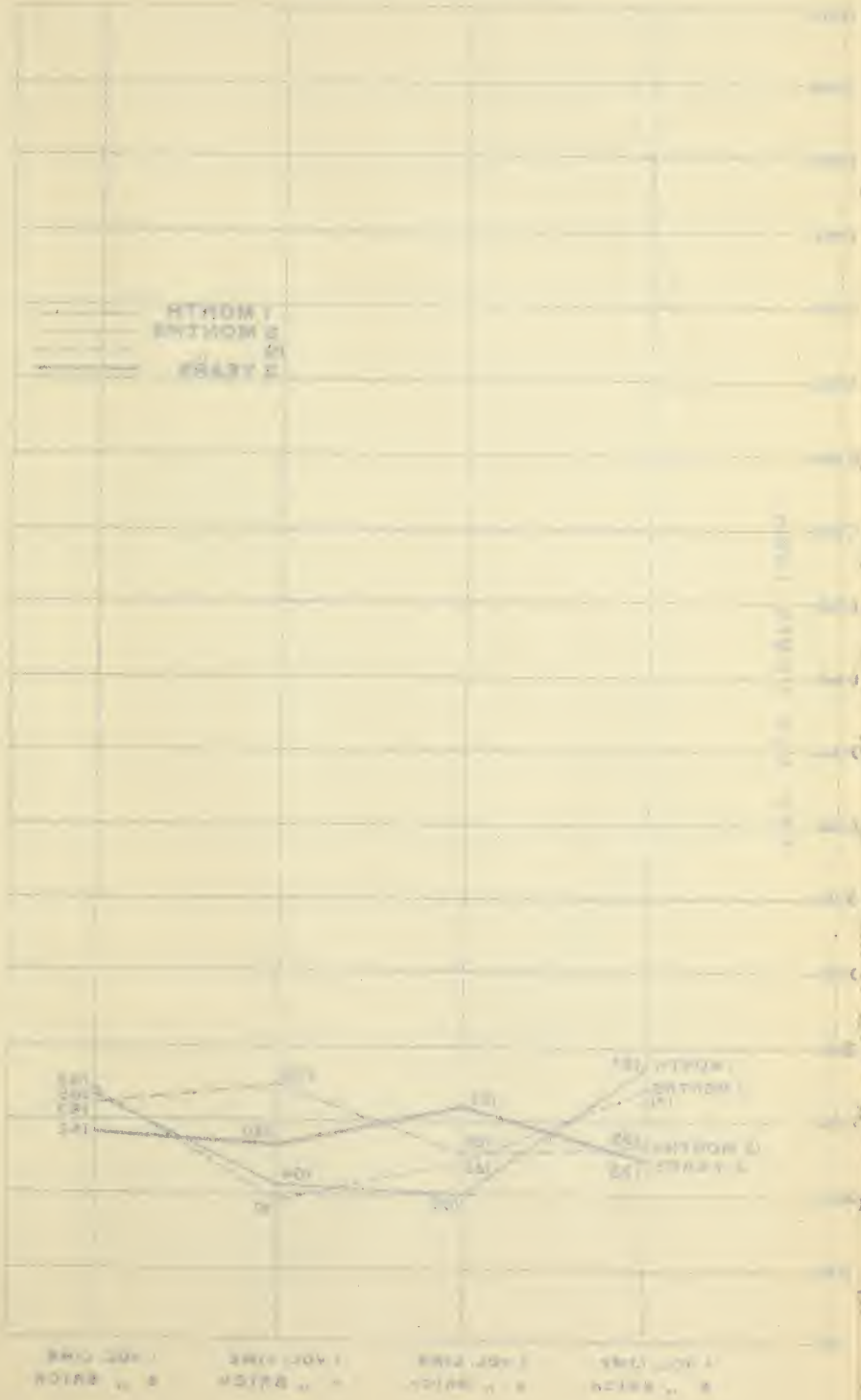
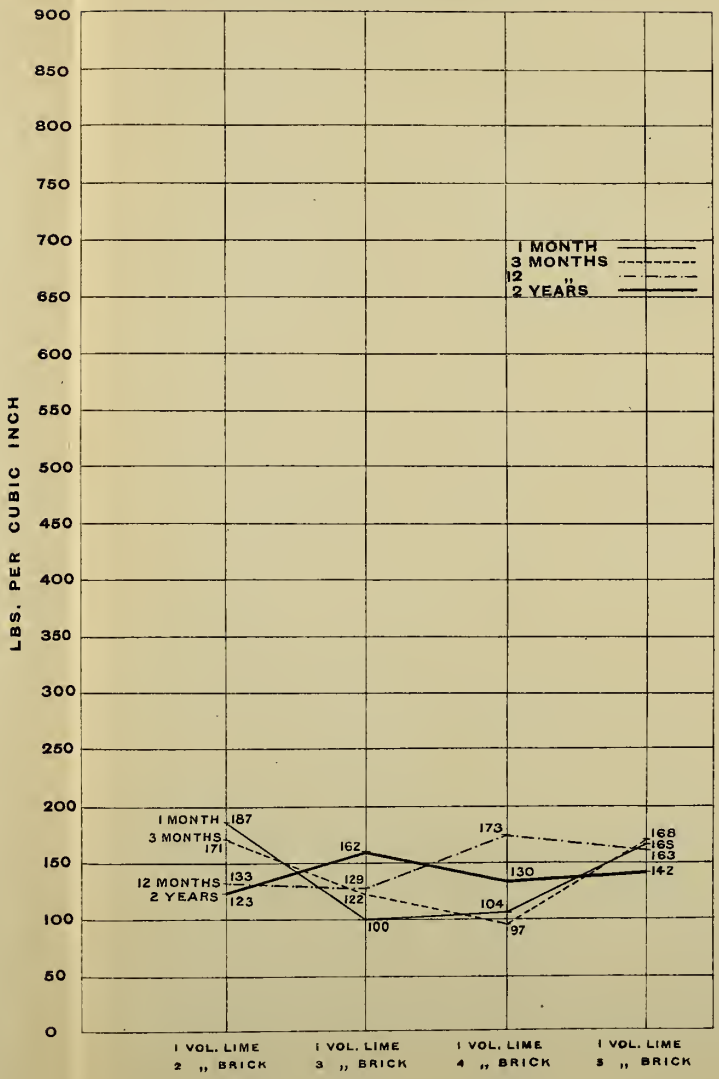


TABLE XIV.

DIAGRAM SERIES Be!

CRUSHING STRENGTH.

DORKING GREY STONE LIME.
+GROUND BRICK.



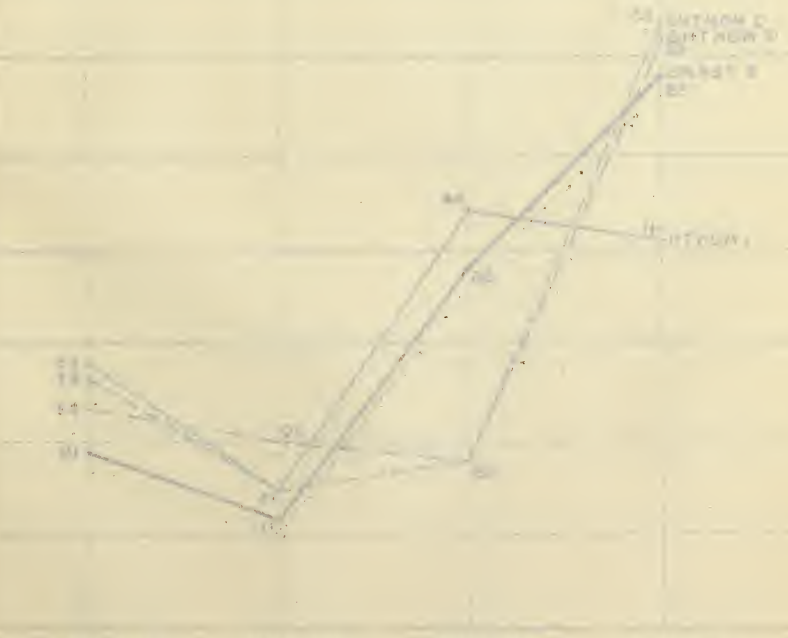
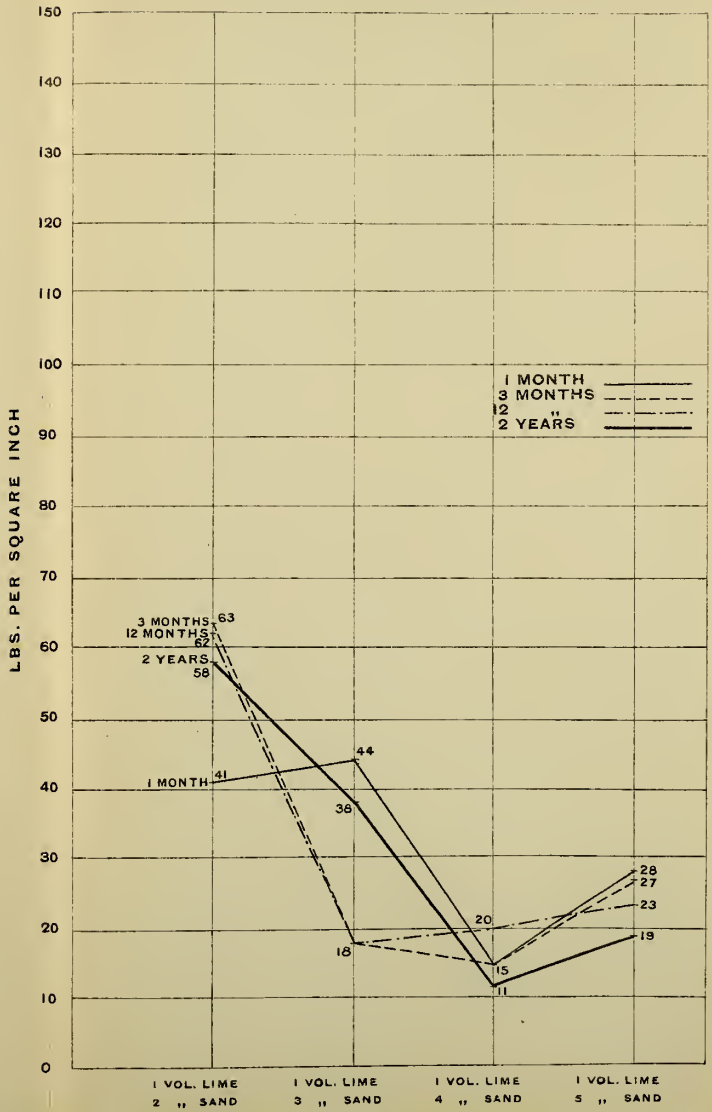


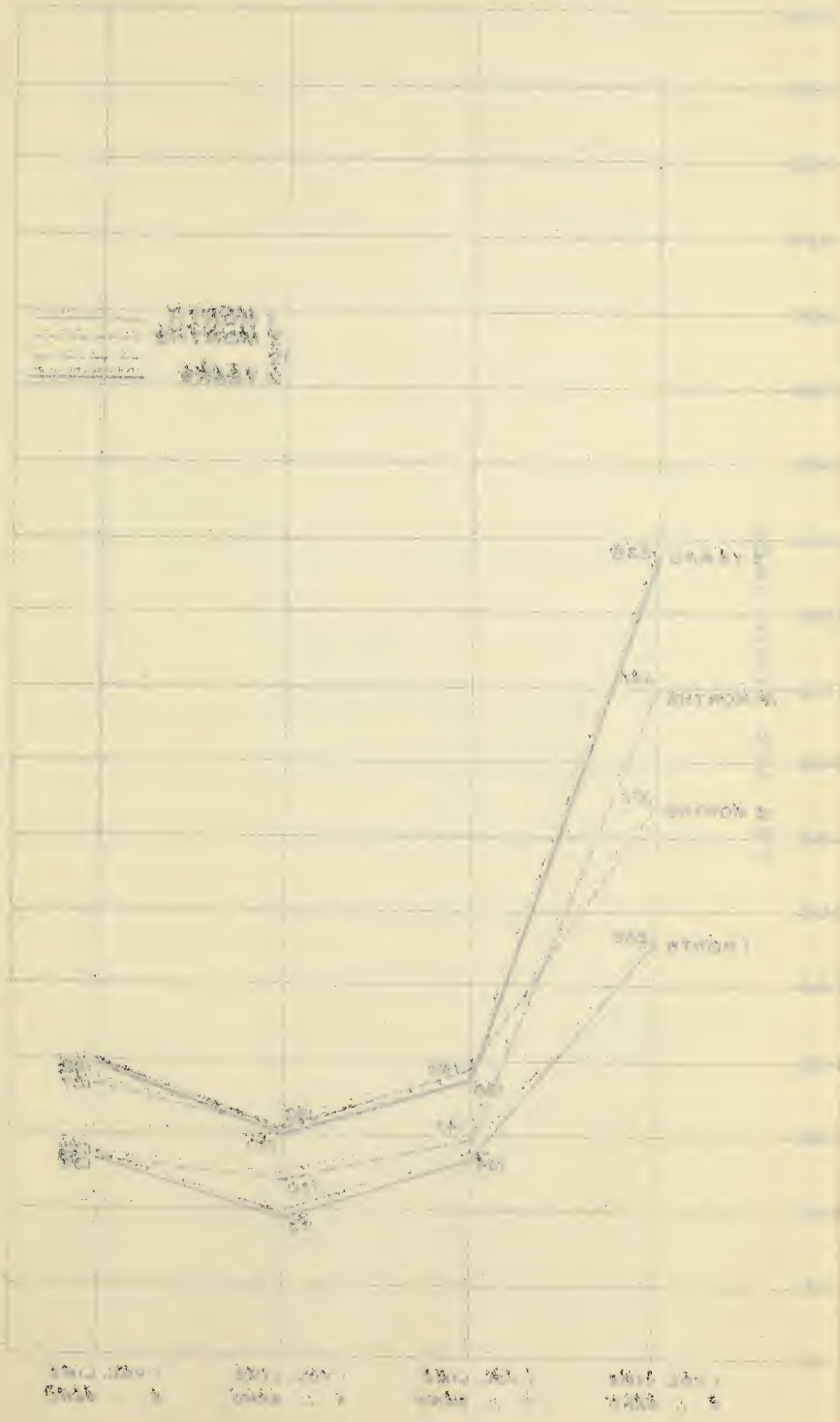
TABLE XV.

DIAGRAM SERIES C.a.

TENSILE STRENGTH.

BLUE LIAS LIME.
+STANDARD SAND.





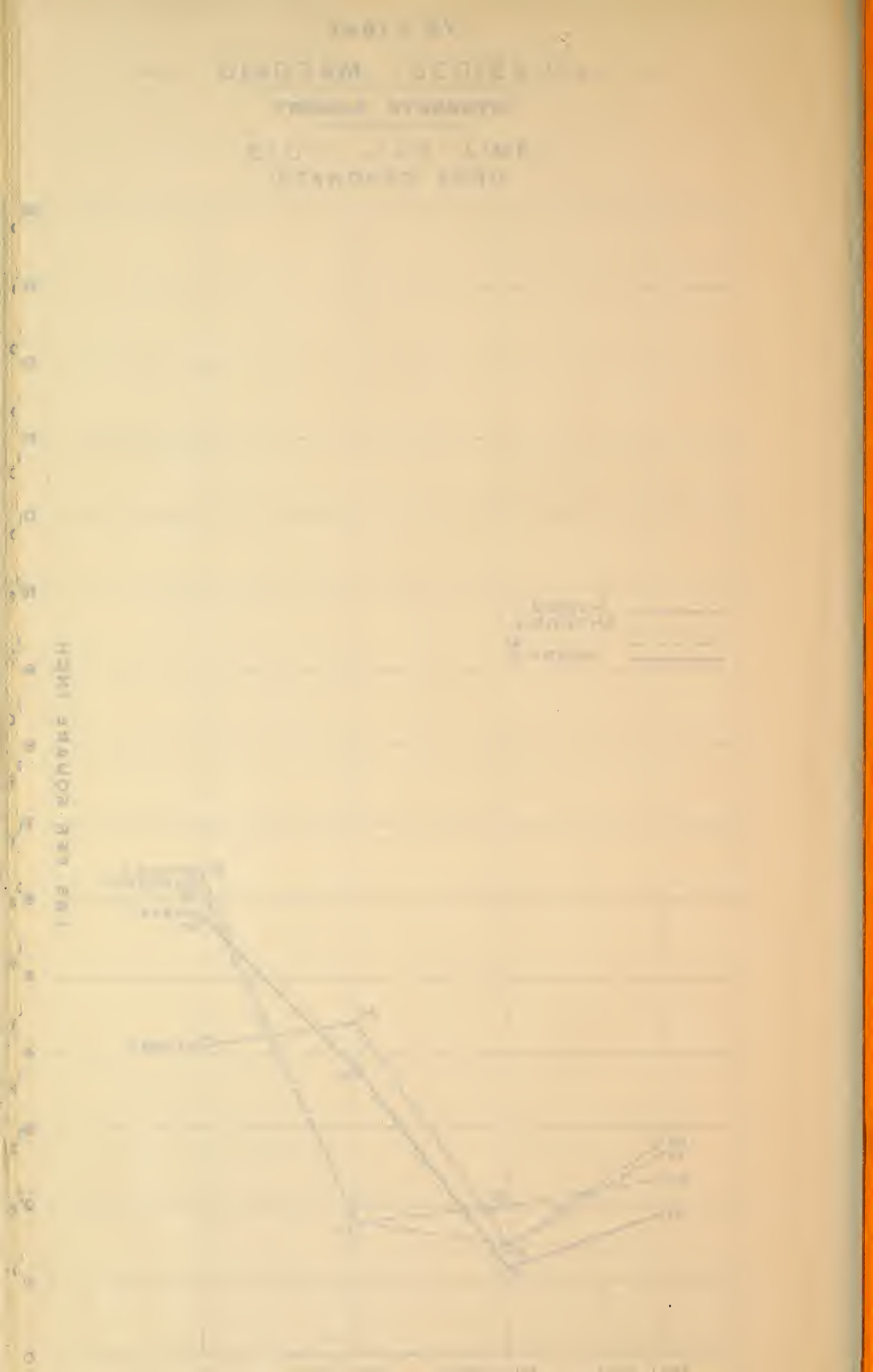
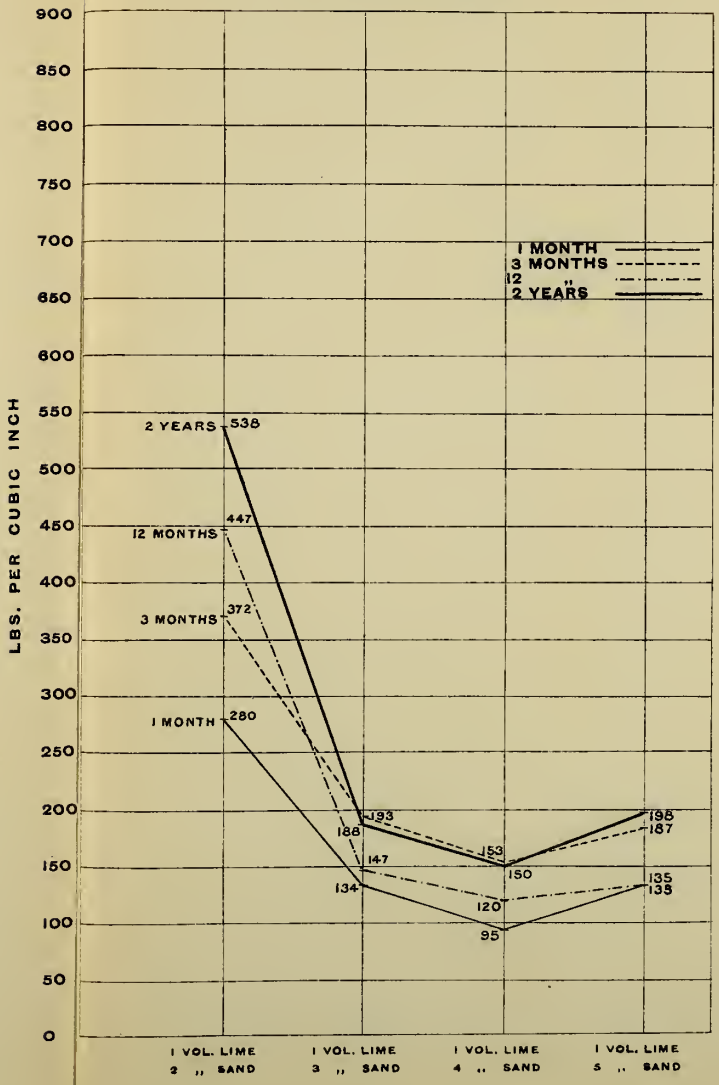


TABLE XV.

DIAGRAM SERIES C.a!

CRUSHING STRENGTH.

BLUE LIAS LIME.
+STANDARD SAND



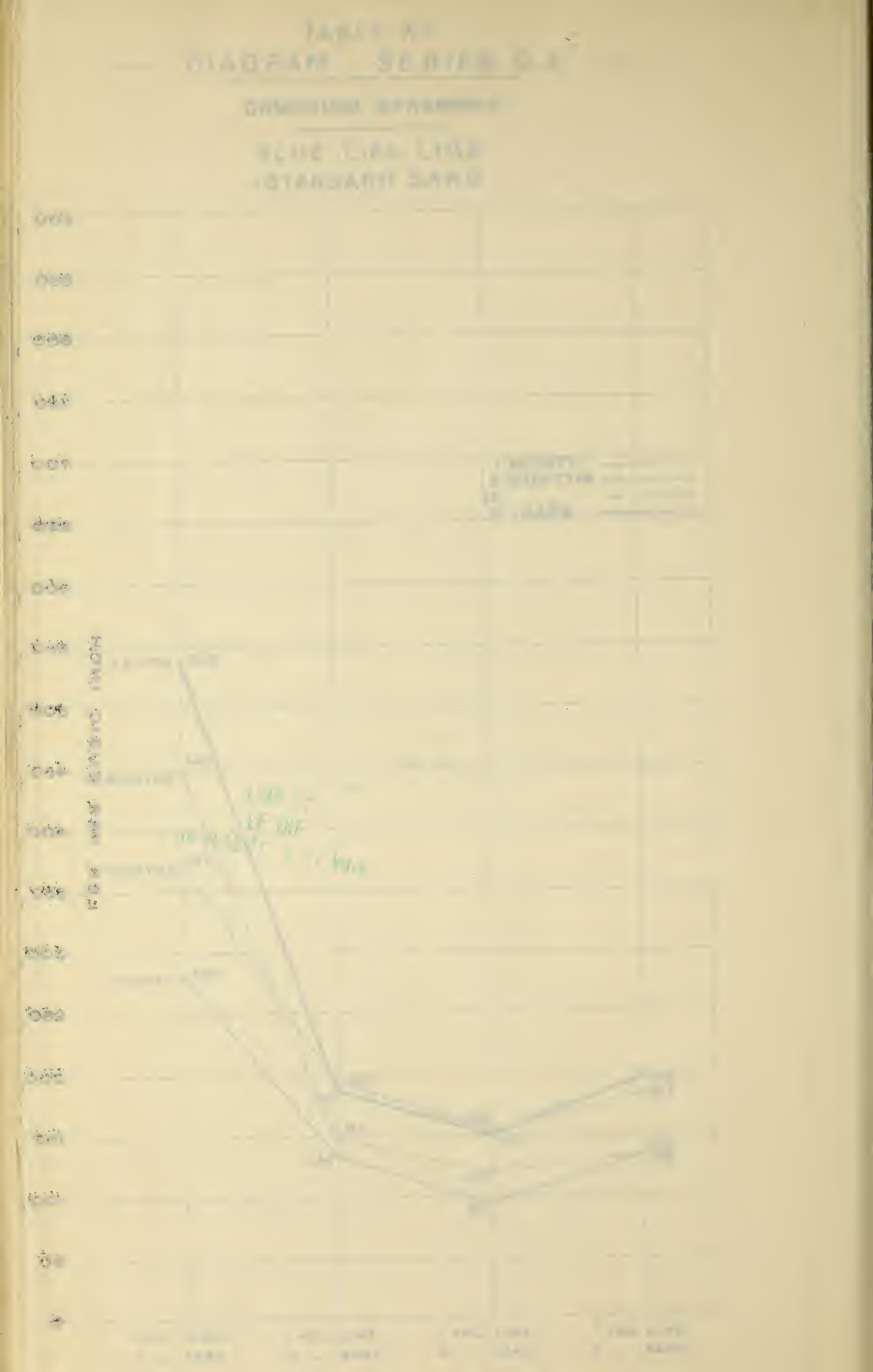
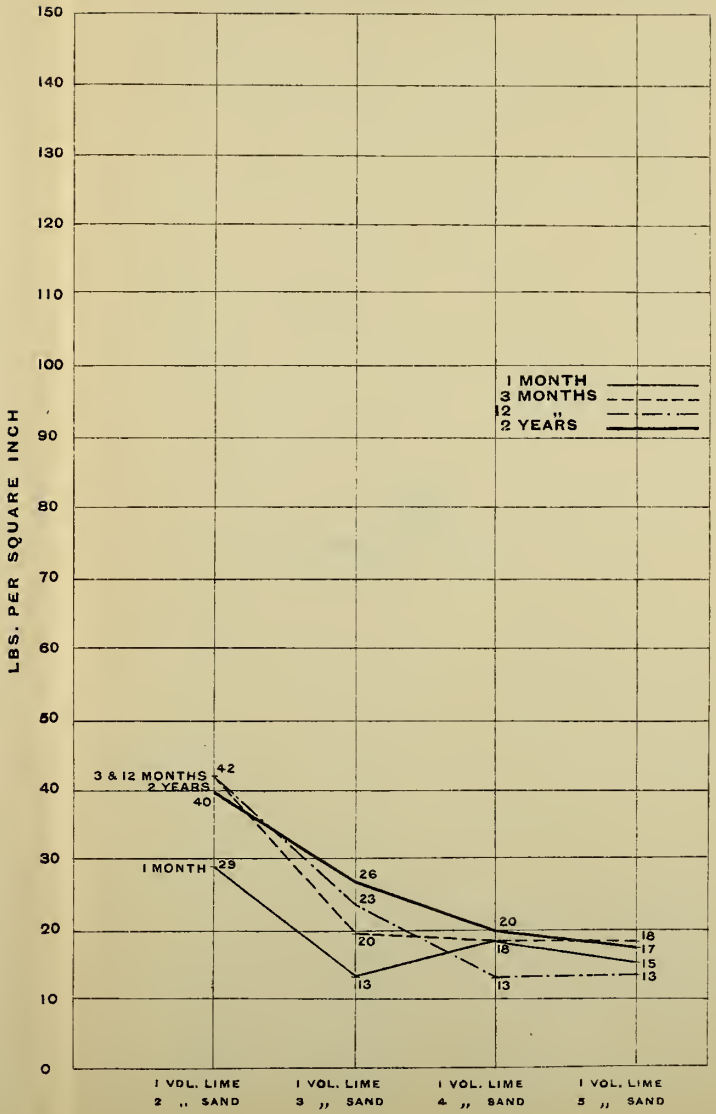


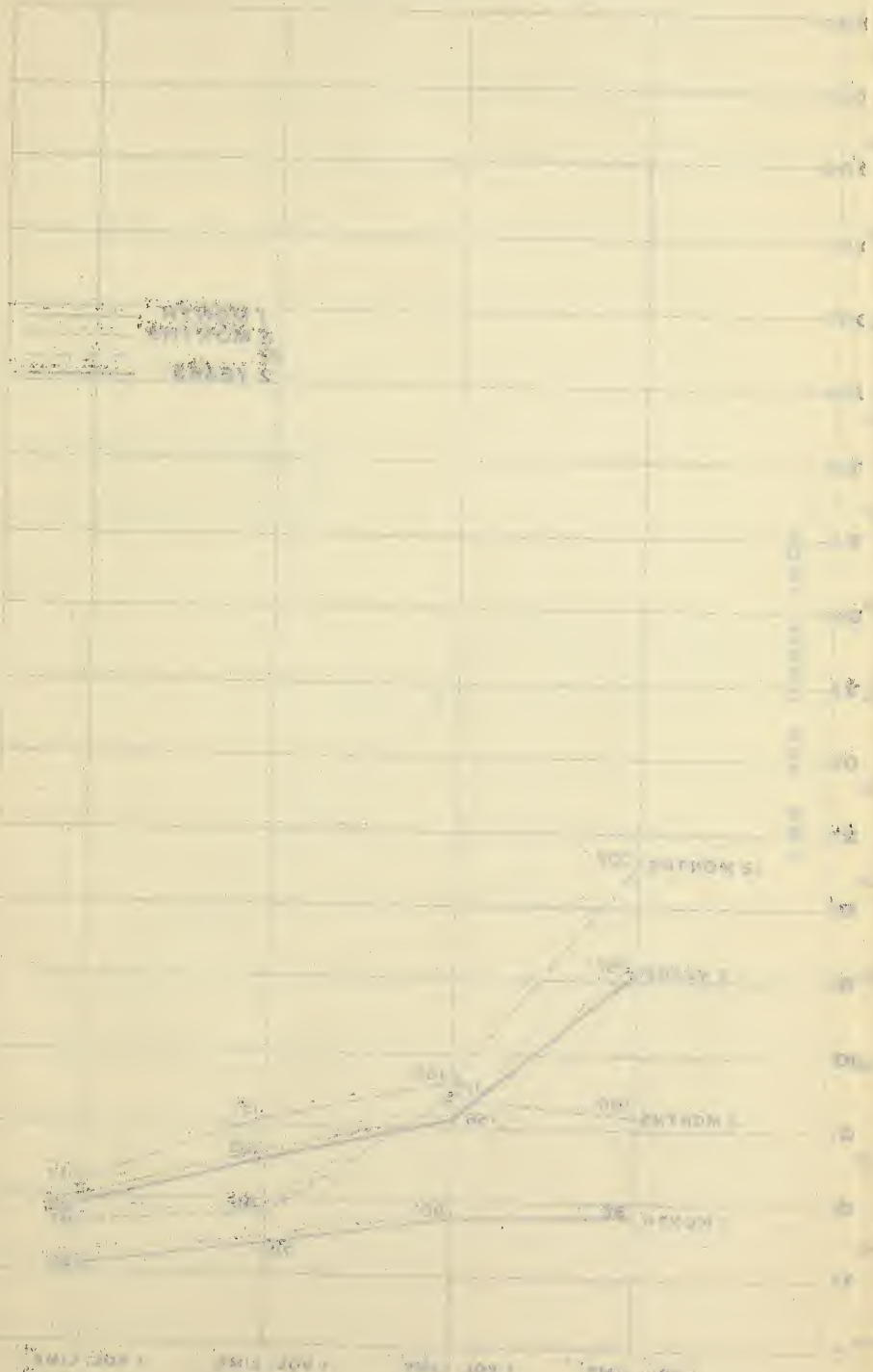
TABLE XV.

DIAGRAM SERIES C.b.

TENSILE STRENGTH.

BLUE LIAS LIME.
+FINE SAND (CHARLTON)





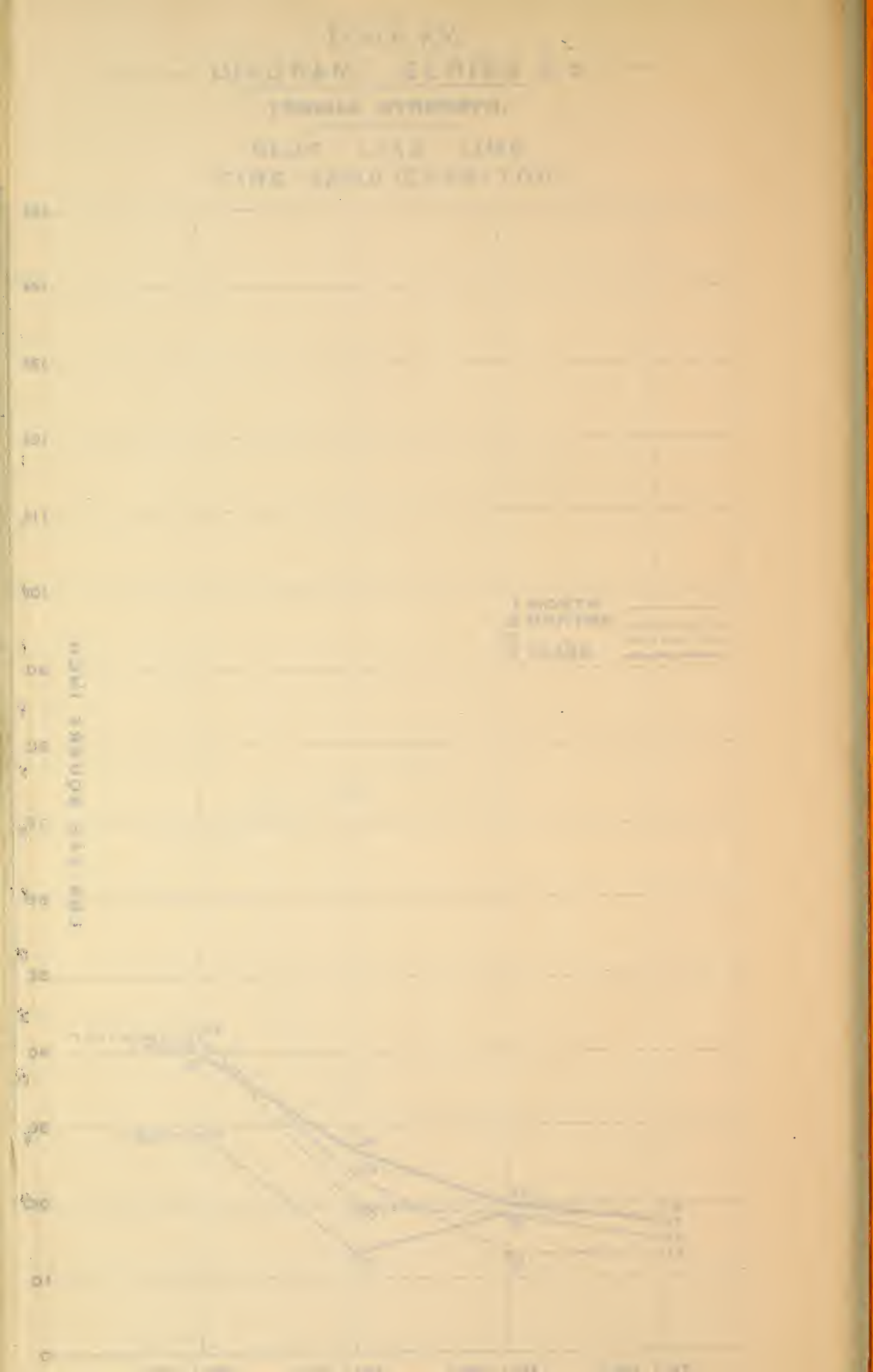


TABLE XV.

DIAGRAM SERIES C.b!

CRUSHING STRENGTH.

BLUE LIAS LIME.
+FINE SAND (CHARLTON)

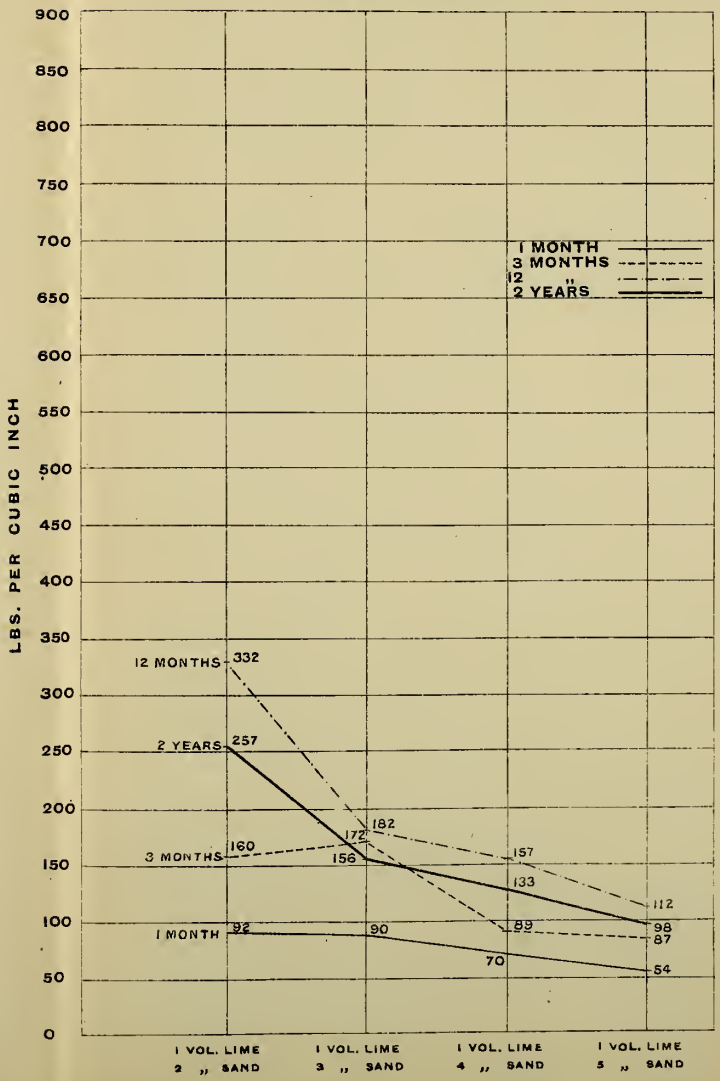


TABLE 6[illegible]

DIAGRAM SERIES U[illegible]

CRUSHING STRENGTH

BLUE LIME LIME

FINE SAND ITHERATOR

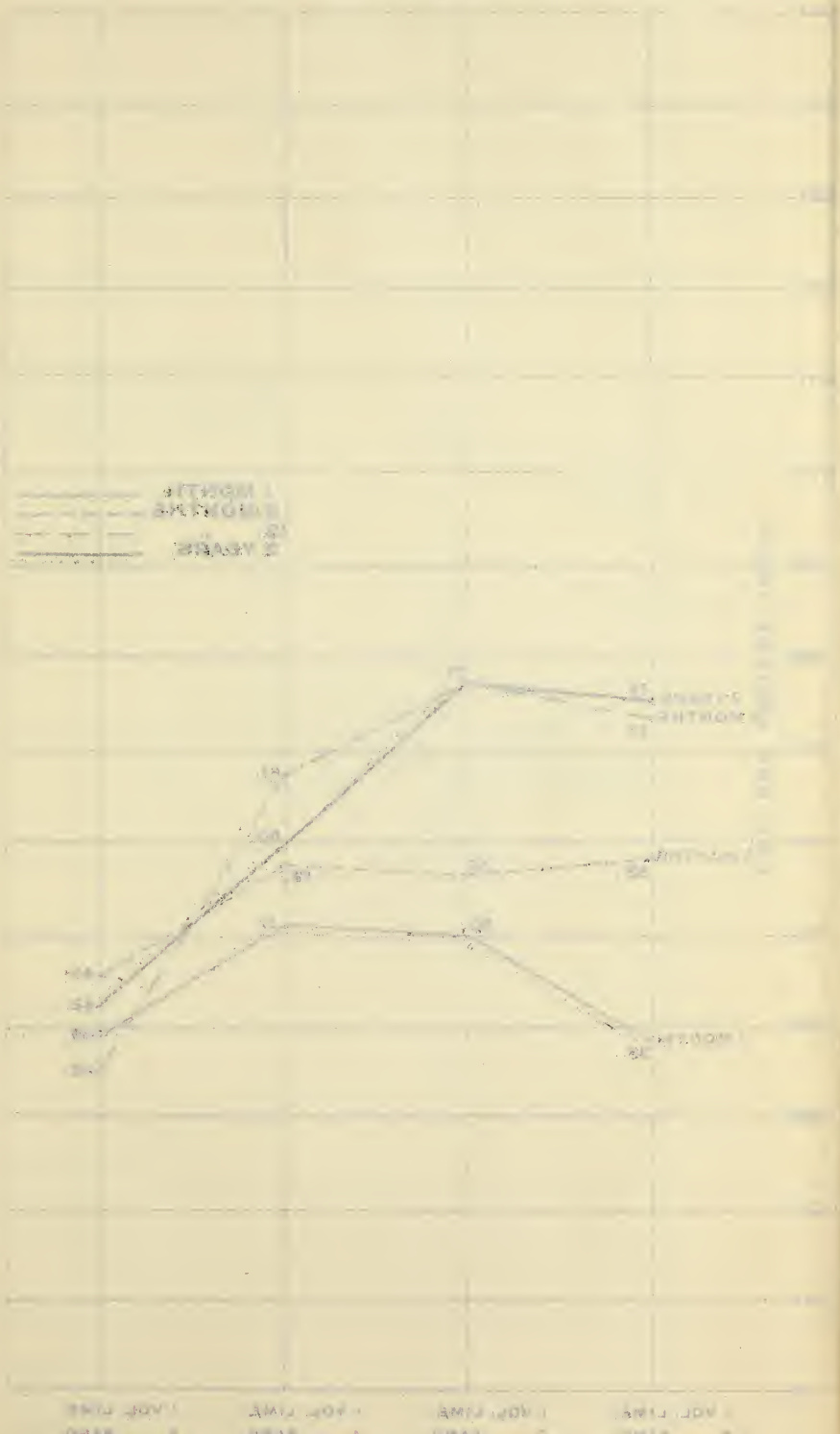
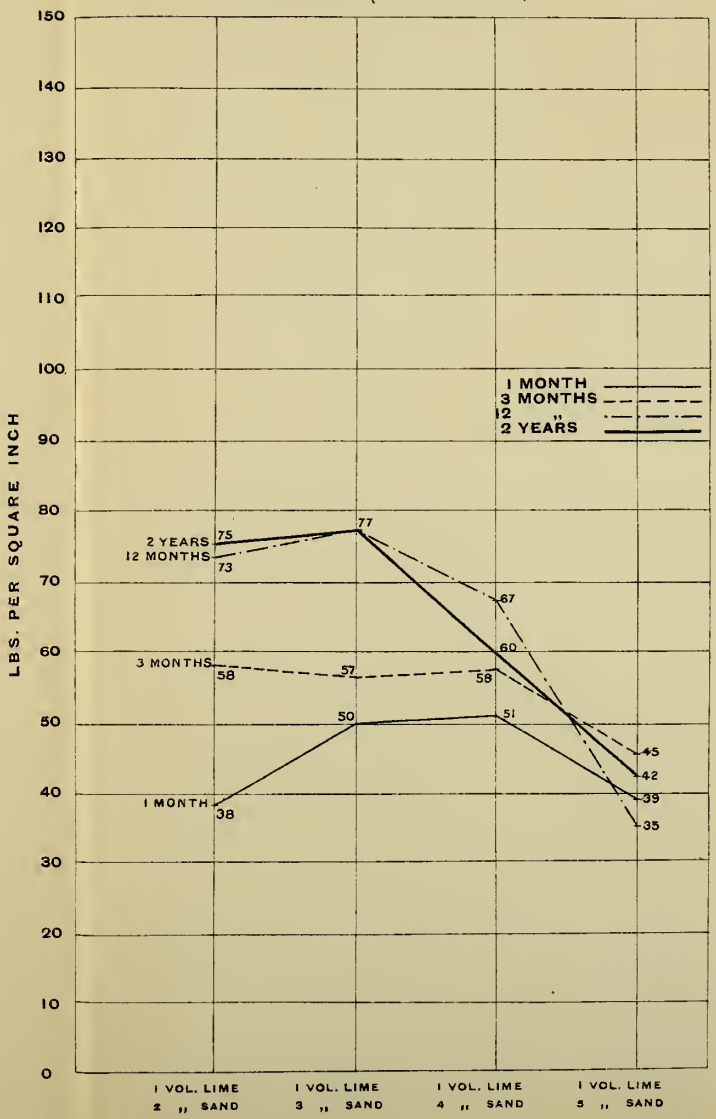


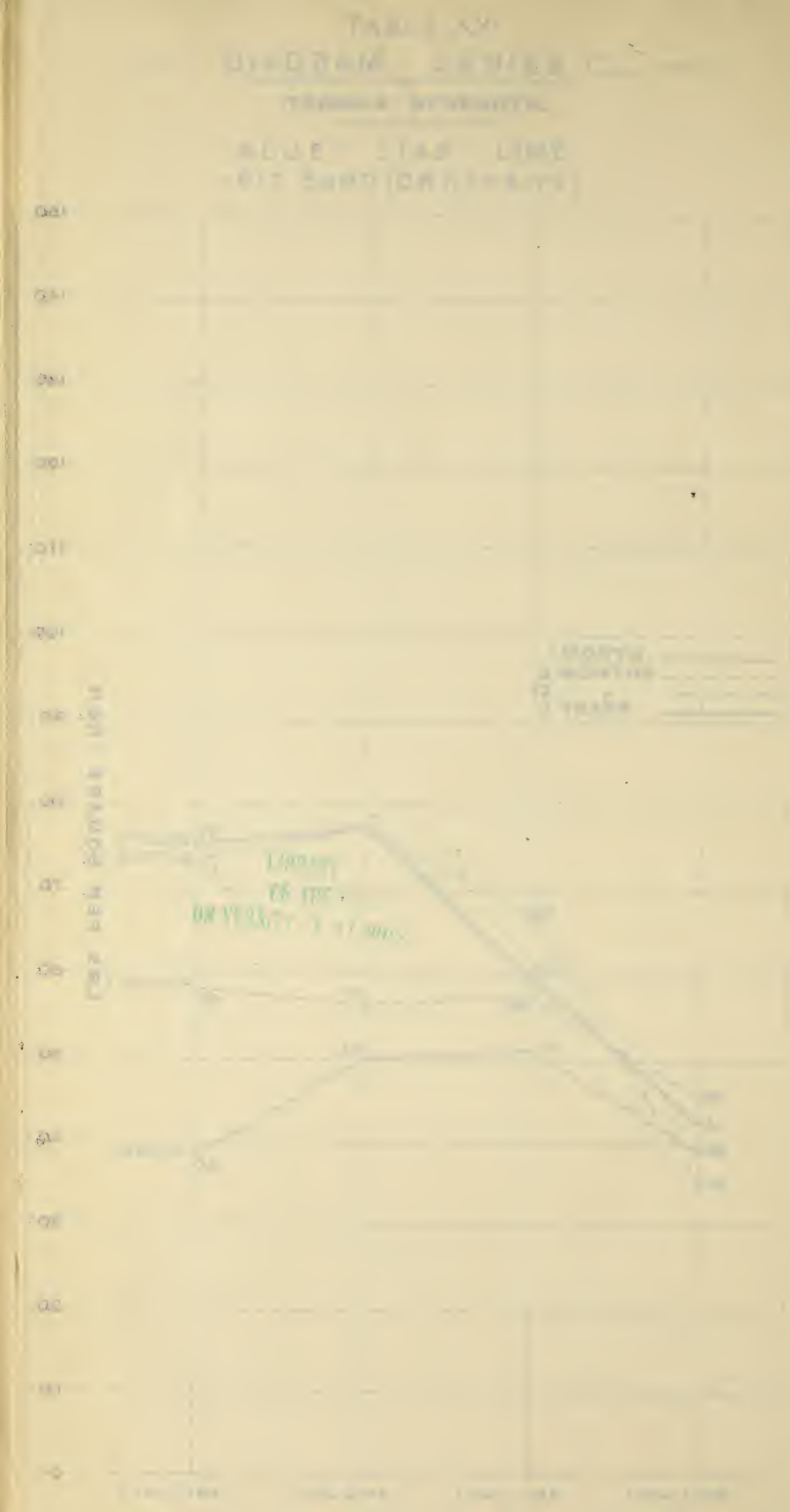
TABLE XV.

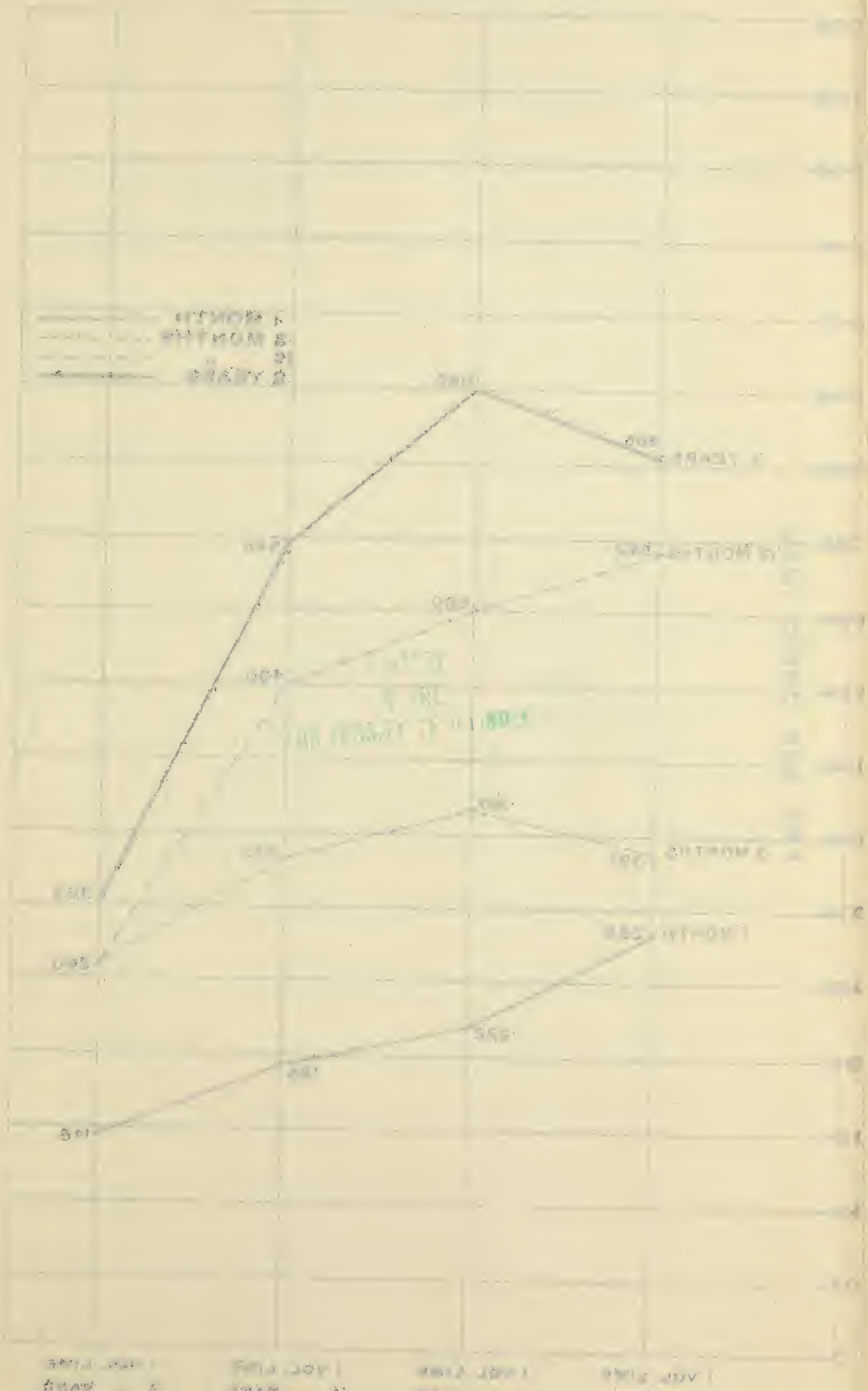
DIAGRAM SERIES C.c.

TENSILE STRENGTH.

BLUE LIAS LIME.
+PIT SAND (ORDINARY)







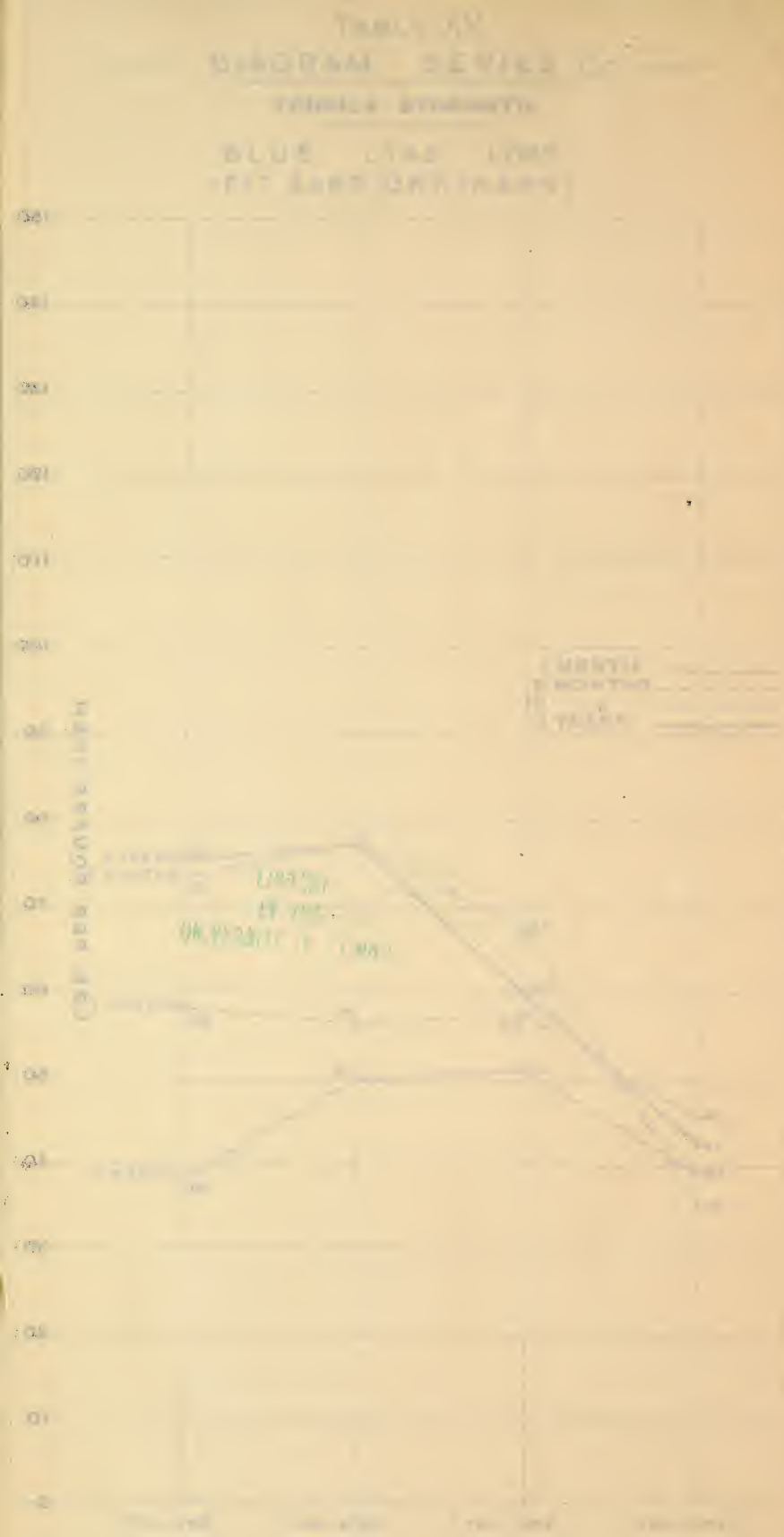
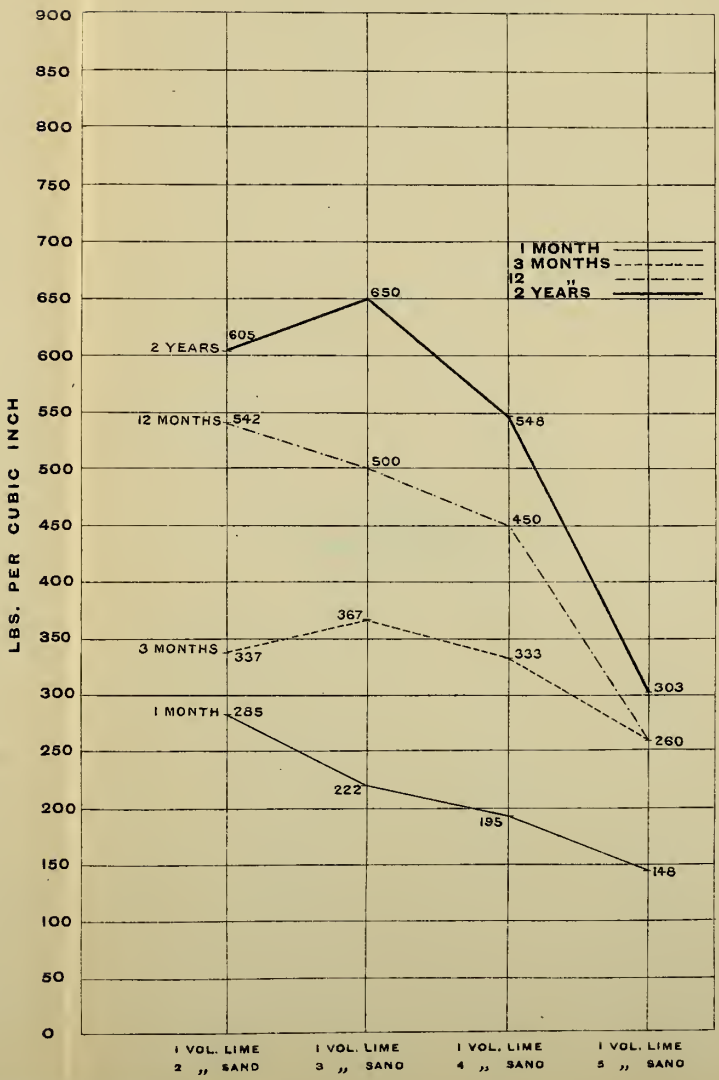


TABLE XV.

DIAGRAM SERIES C.c!

CRUSHING STRENGTH.

BLUE LIAS LIME.
+PIT SAND (ORDINARY)



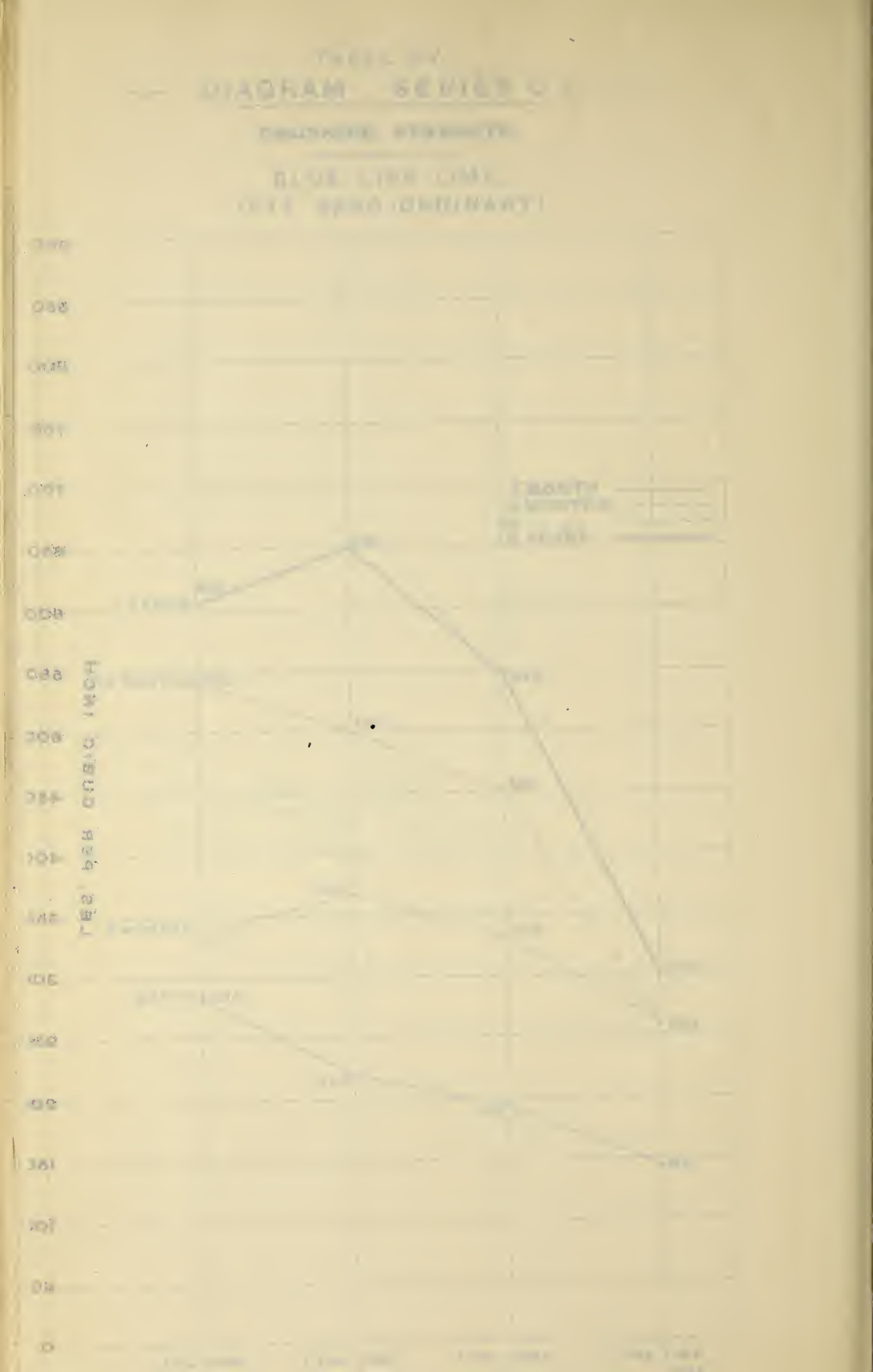


TABLE XV

DIAGRAM SERIES C.d.

TENSILE STRENGTH.

BLUE LIAS LIME
: THAMES SAND

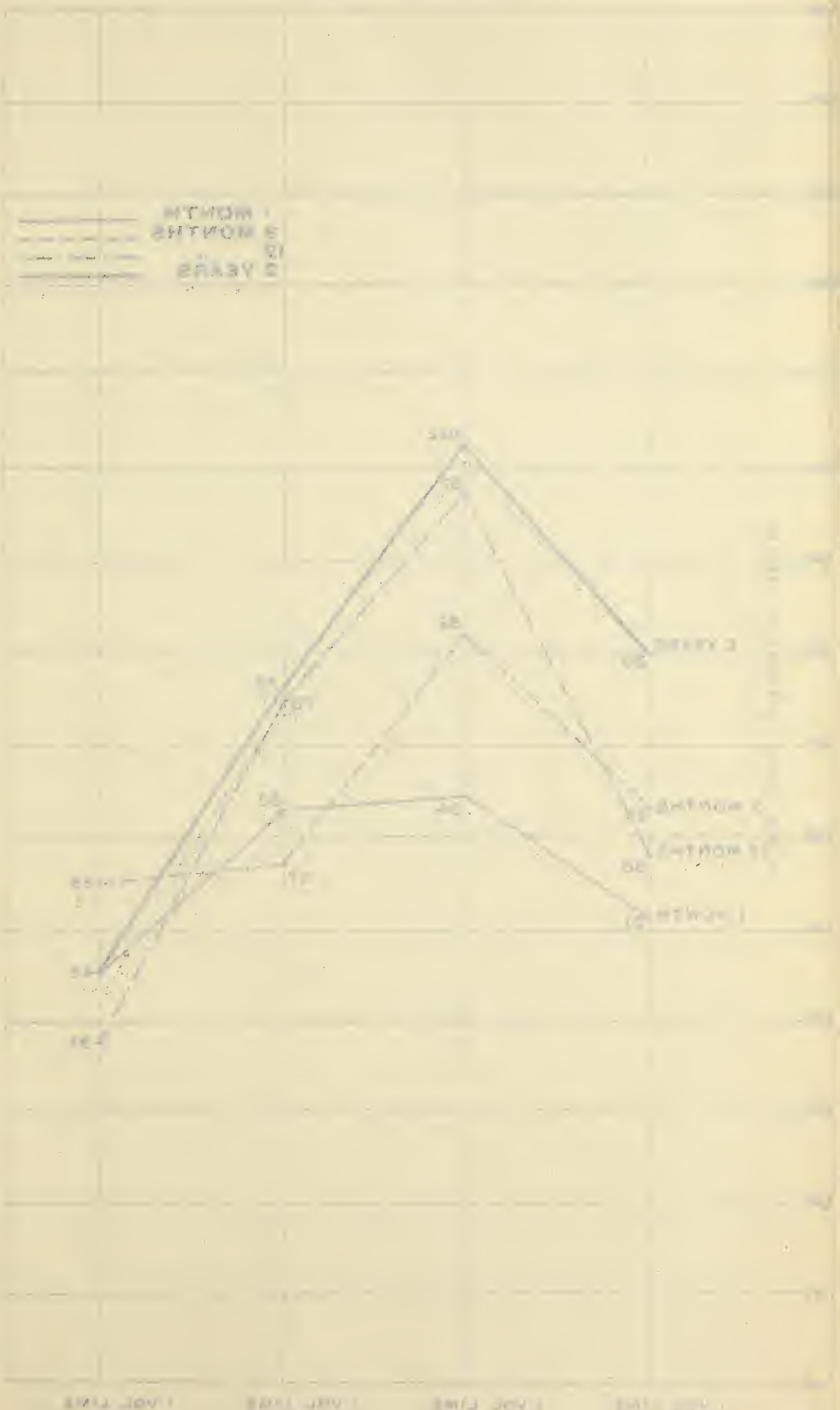
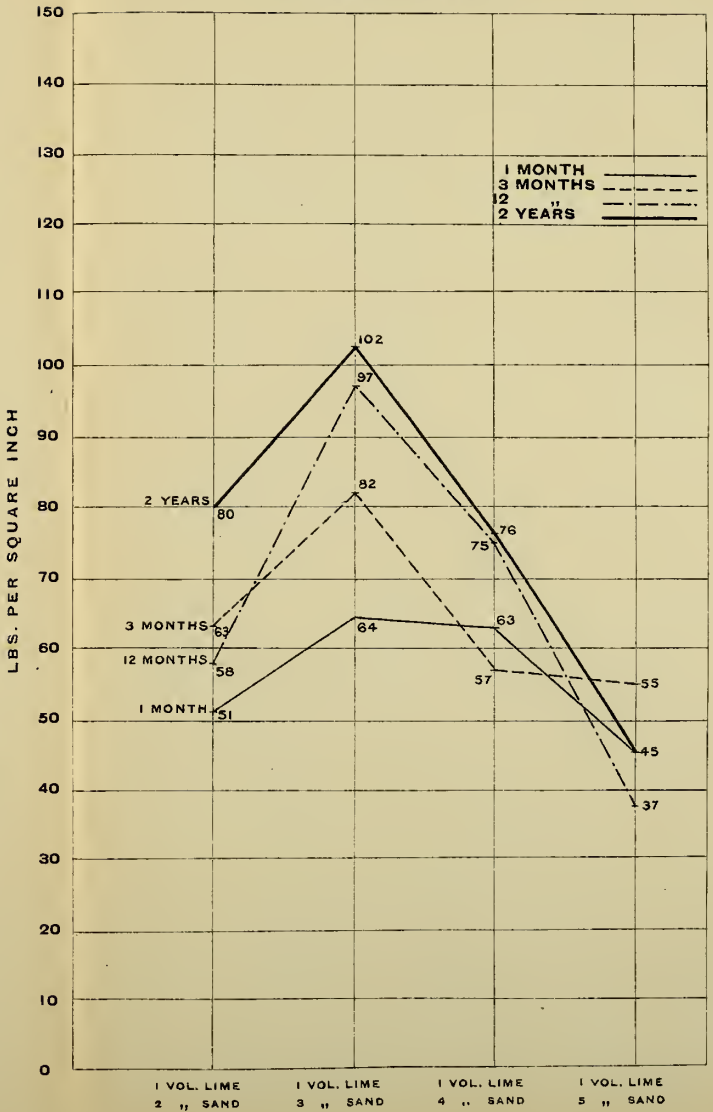


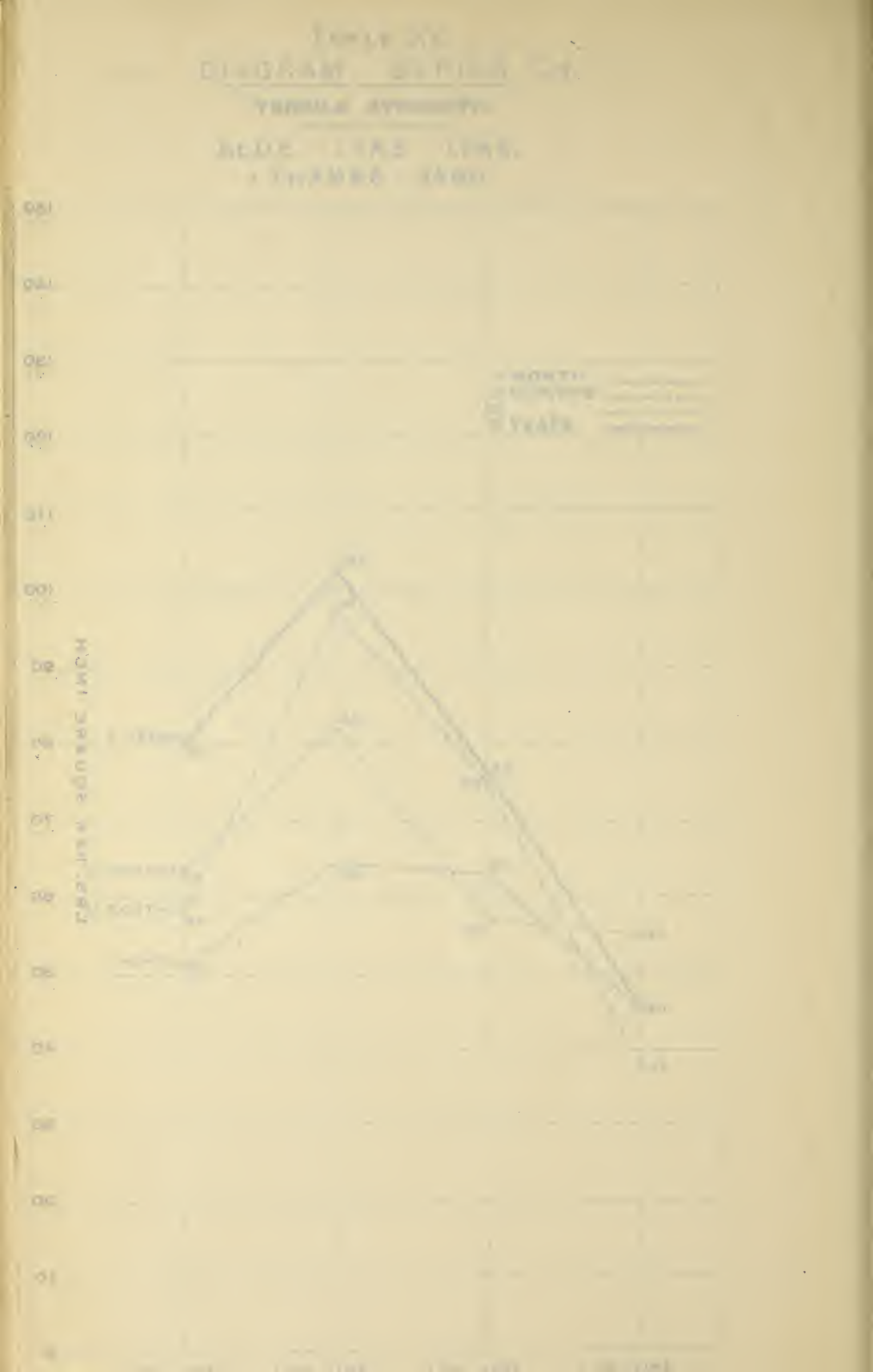
TABLE XV.

DIAGRAM SERIES C.d.

TENSILE STRENGTH.

BLUE LIAS LIME.
+ THAMES SAND.





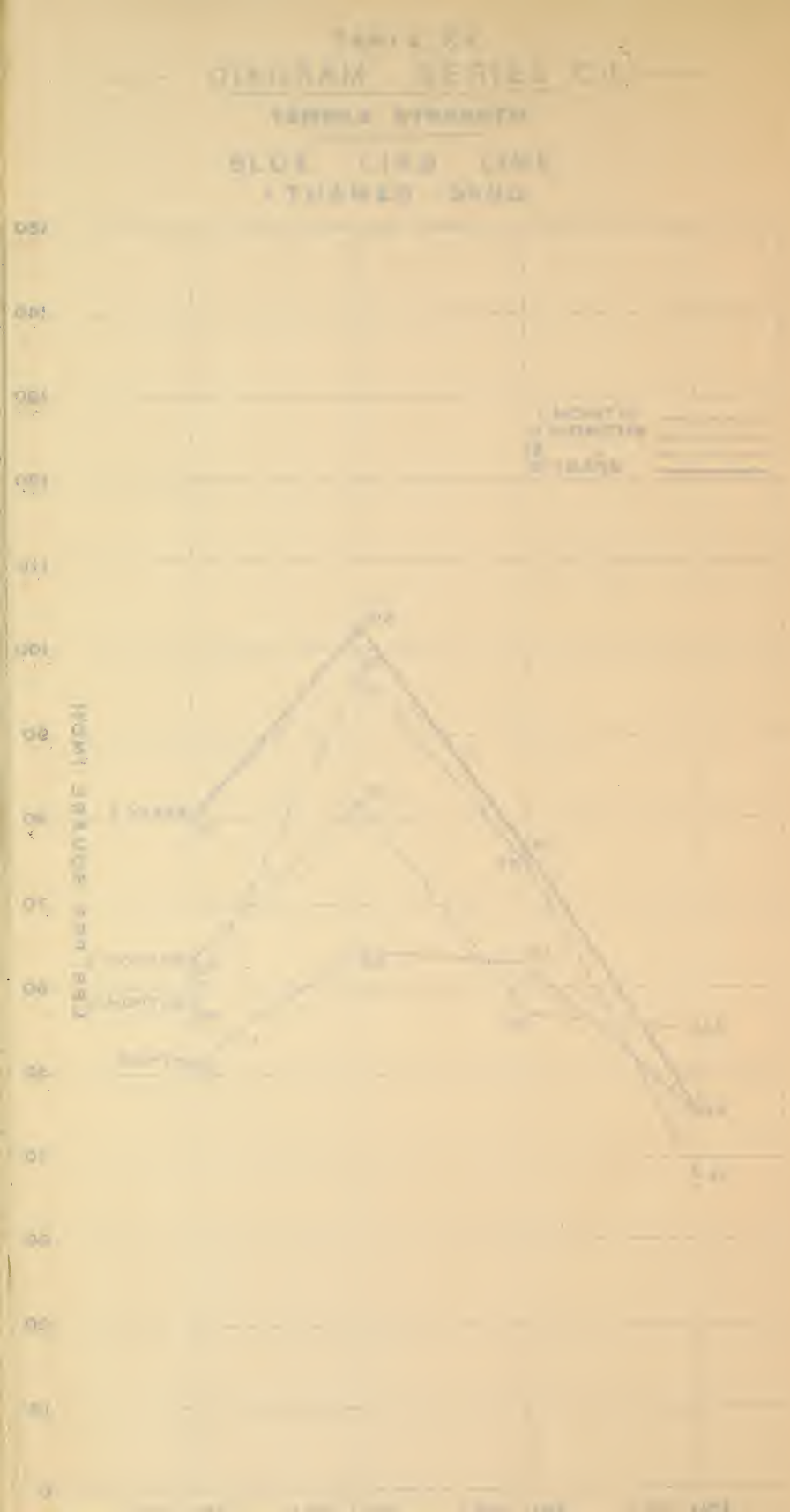
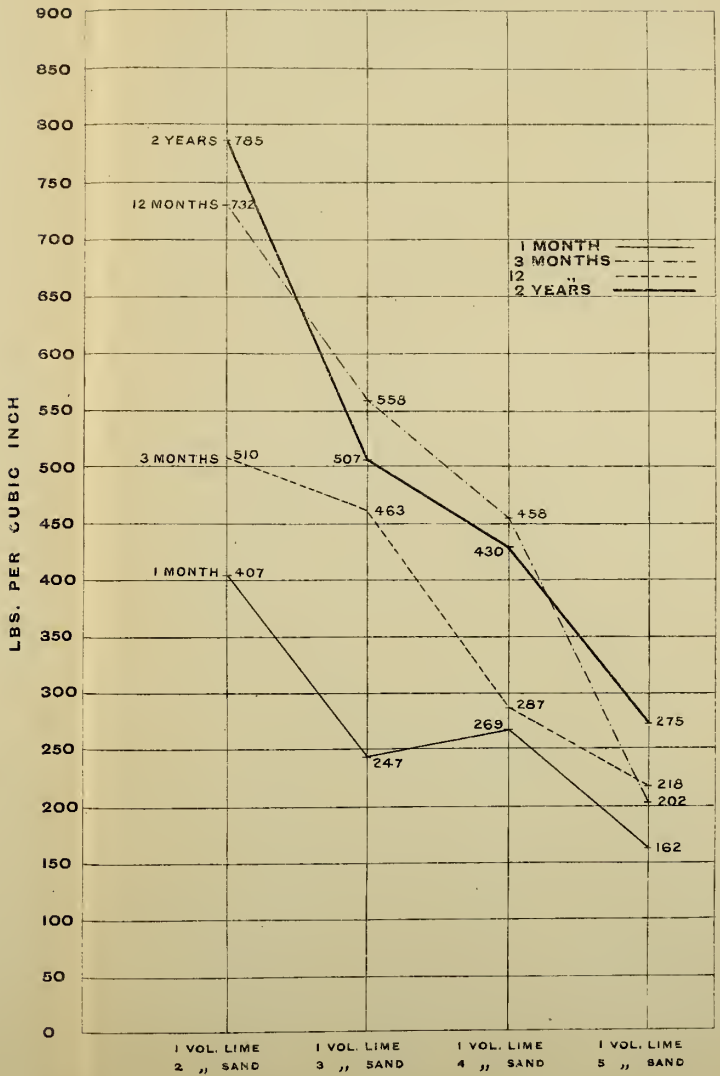


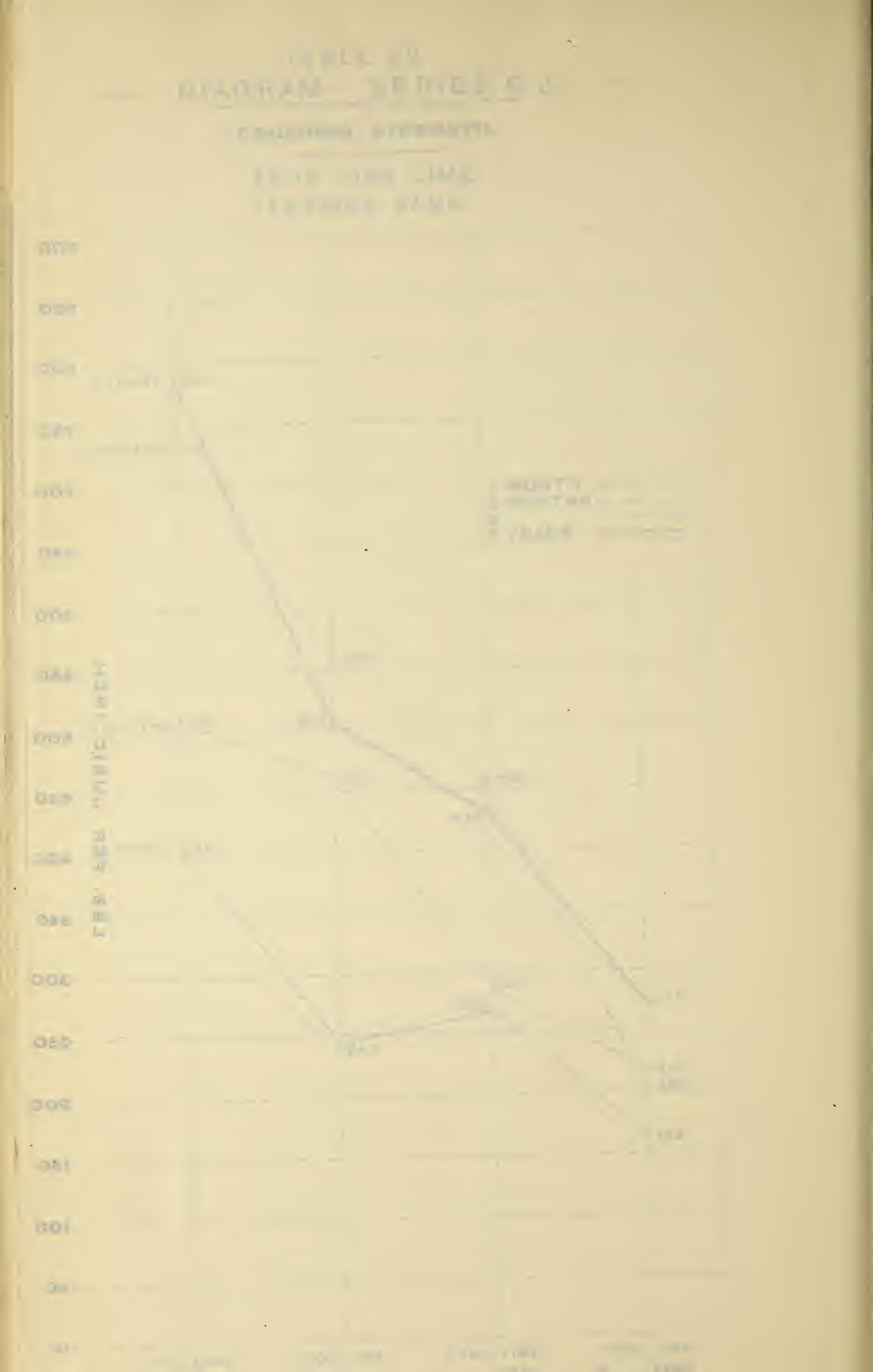
TABLE XV.

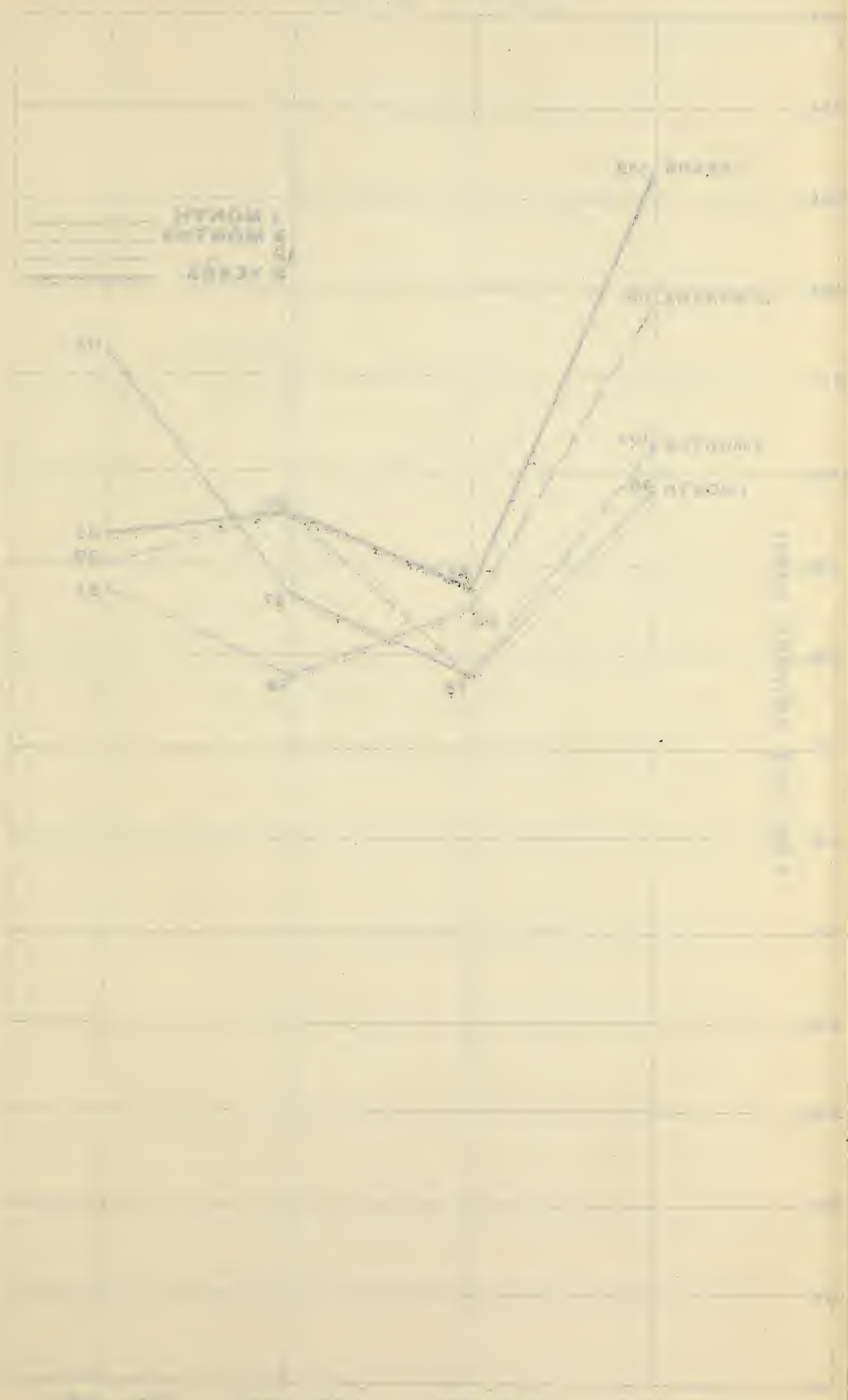
DIAGRAM SERIES C.d!

CRUSHING STRENGTH.

BLUE LIAS LIME.
+THAMES SAND.







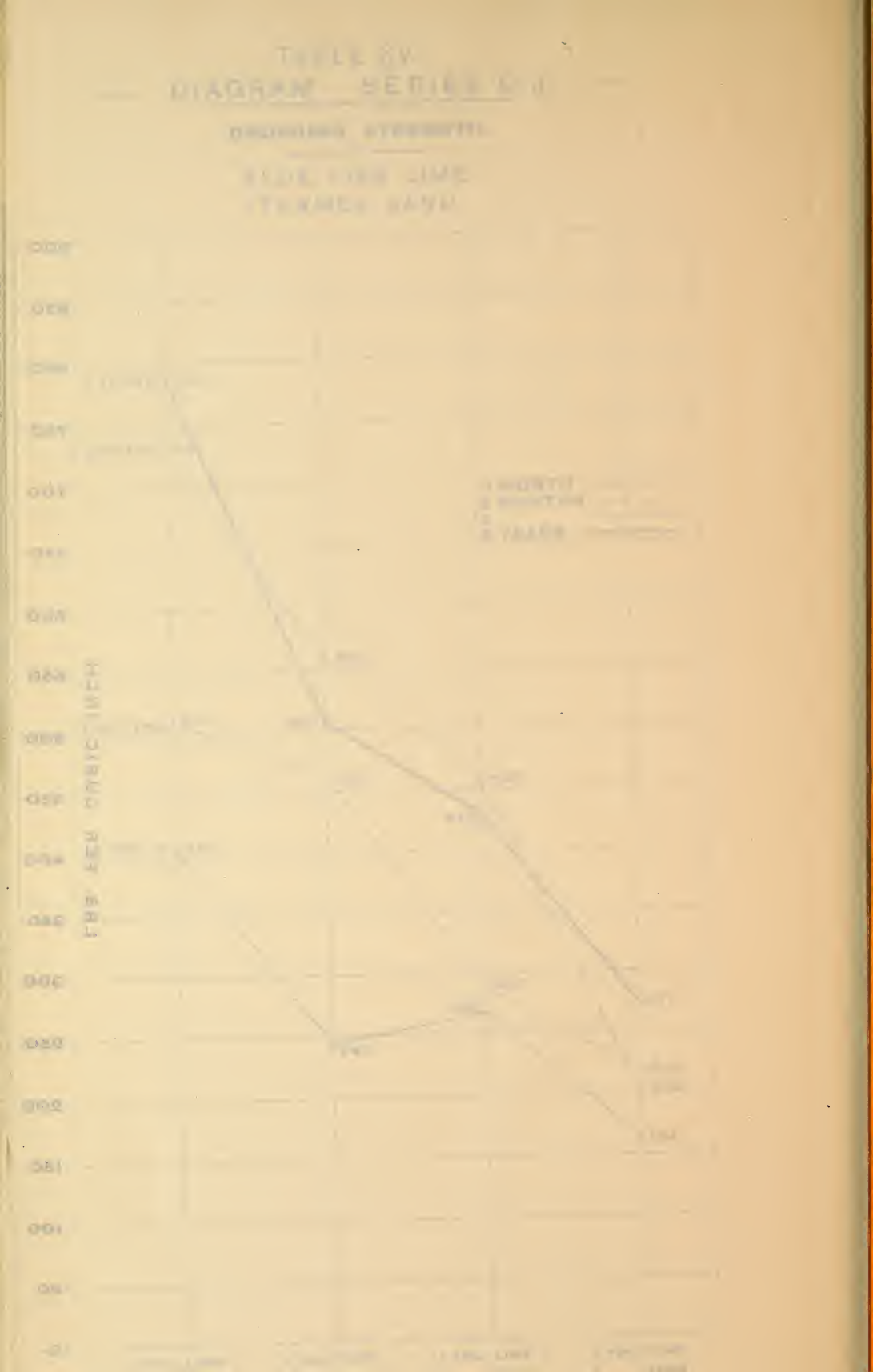
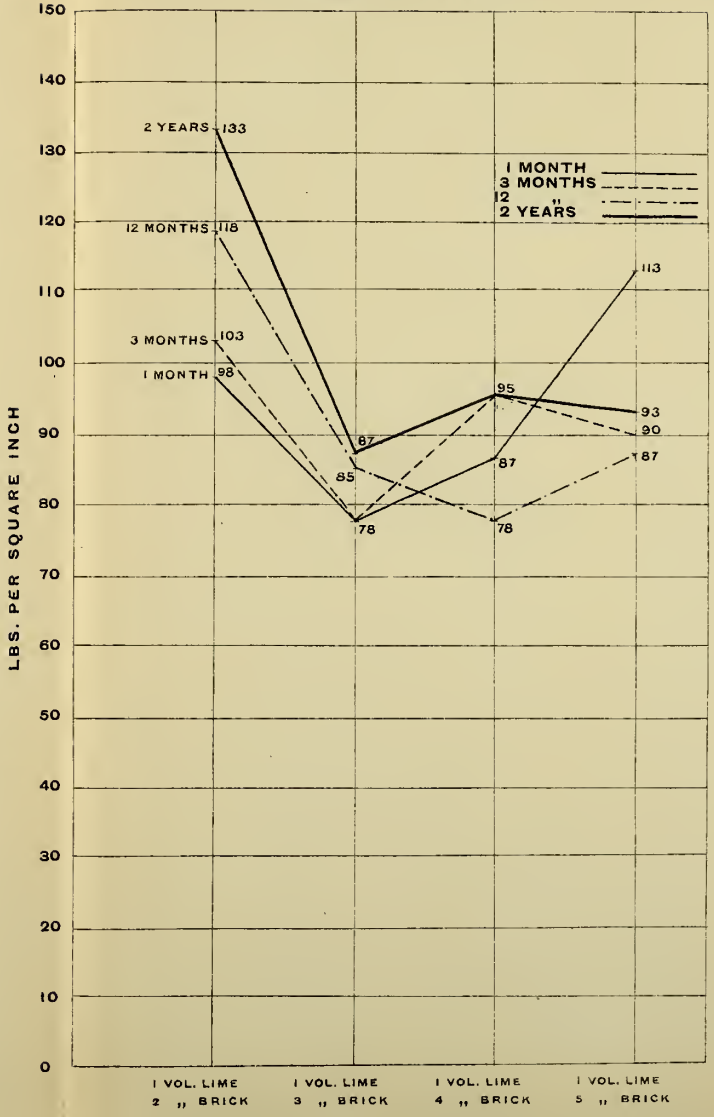


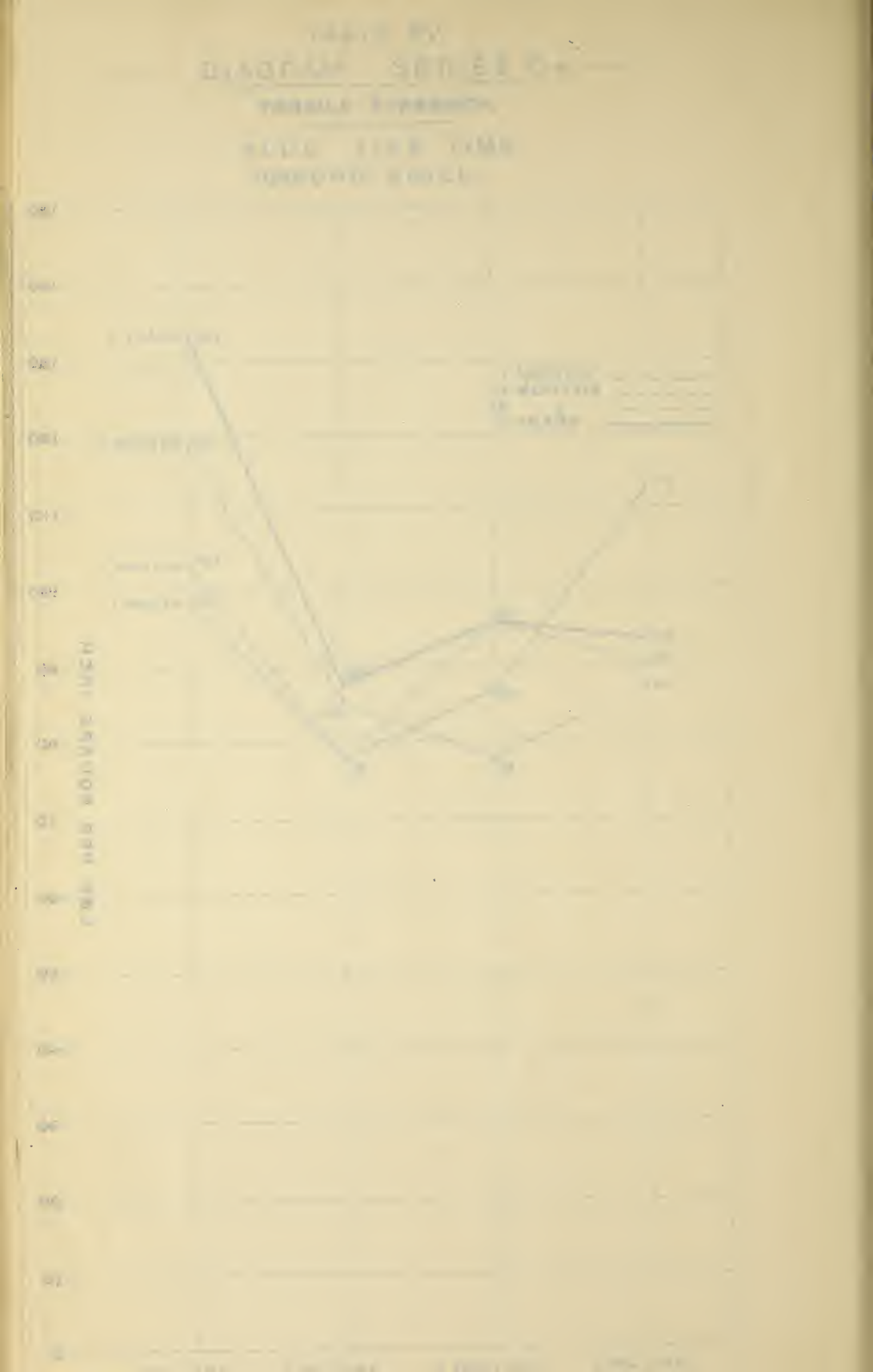
TABLE XV.

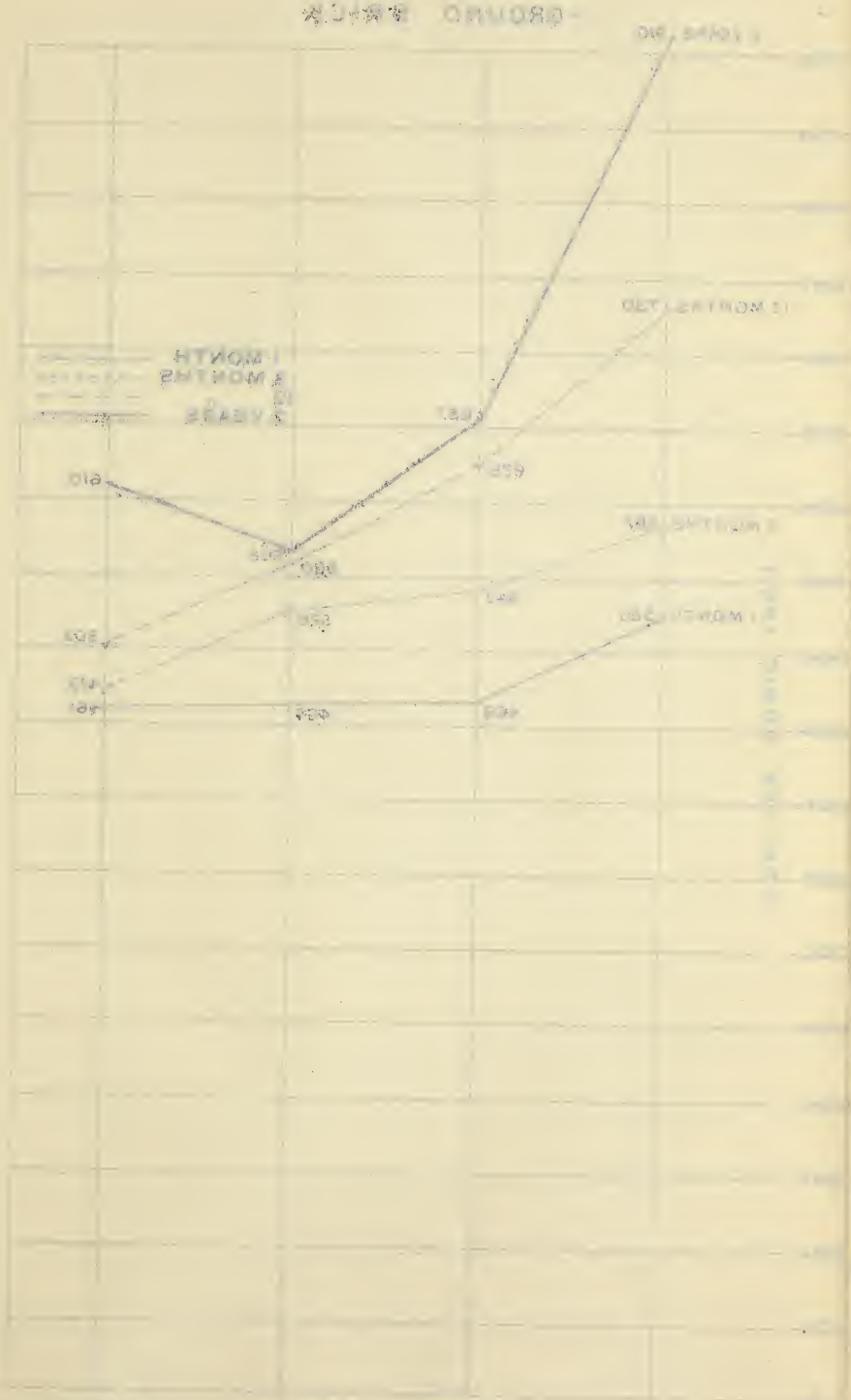
DIAGRAM SERIES C.e.

TENSILE STRENGTH.

BLUE LIAS LIME.
+GROUND BRICK.







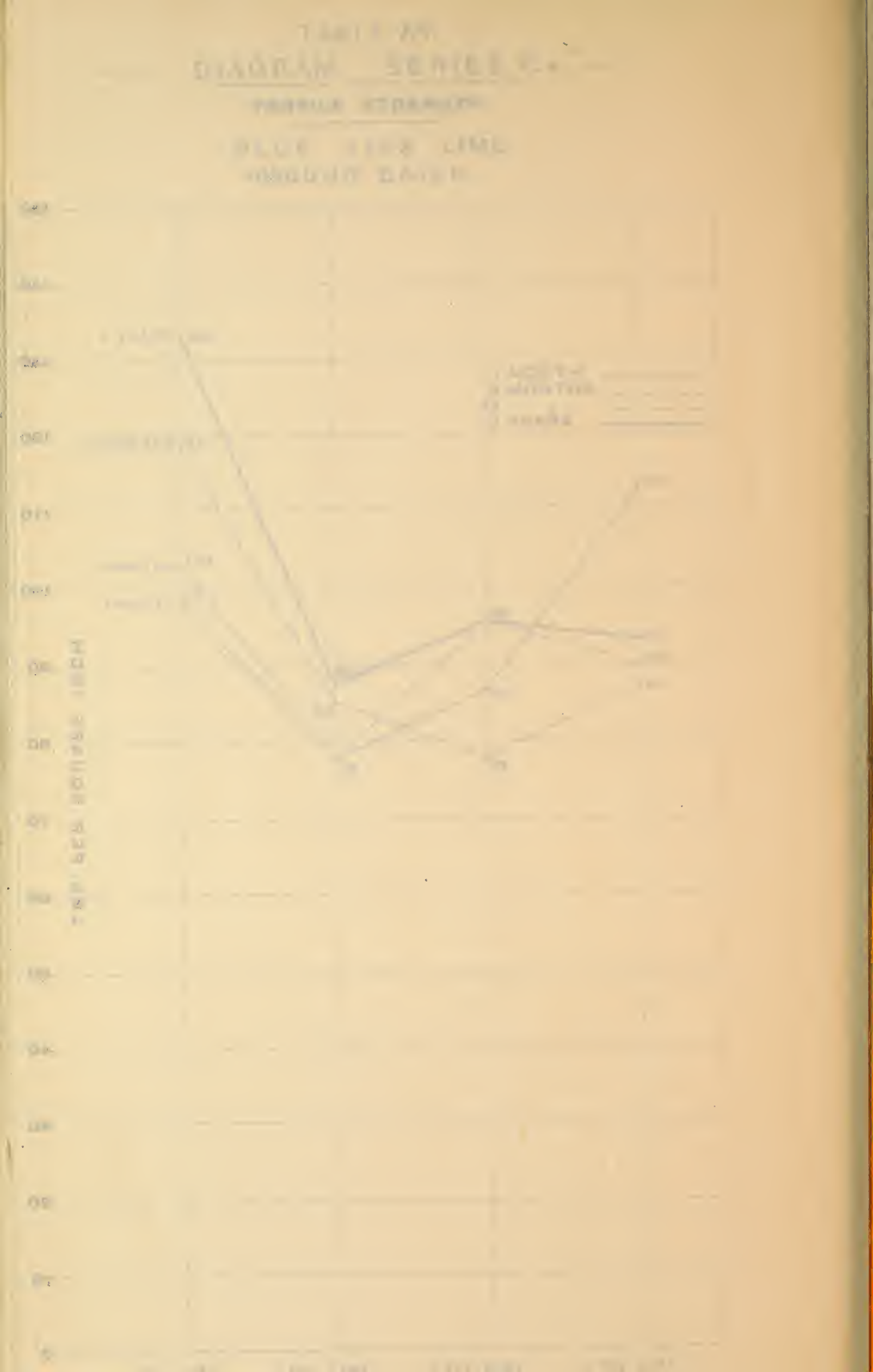
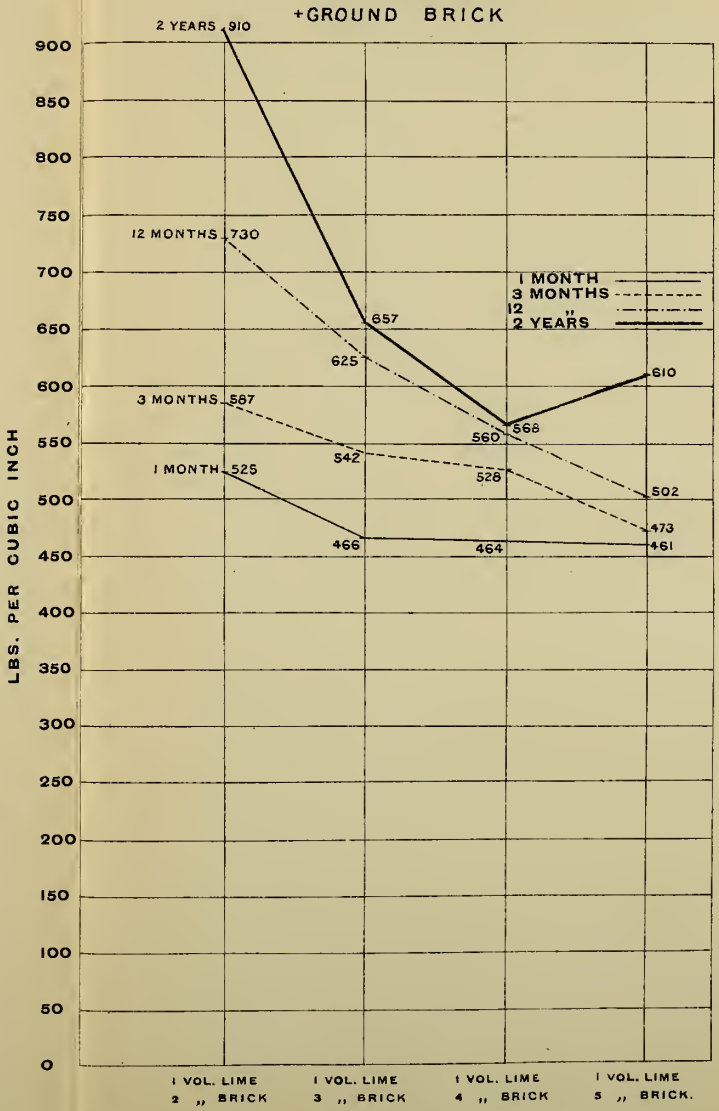


TABLE XV.

DIAGRAM SERIES C. e!

CRUSHING STRENGTH.

BLUE LIAS LIME.
+GROUND BRICK



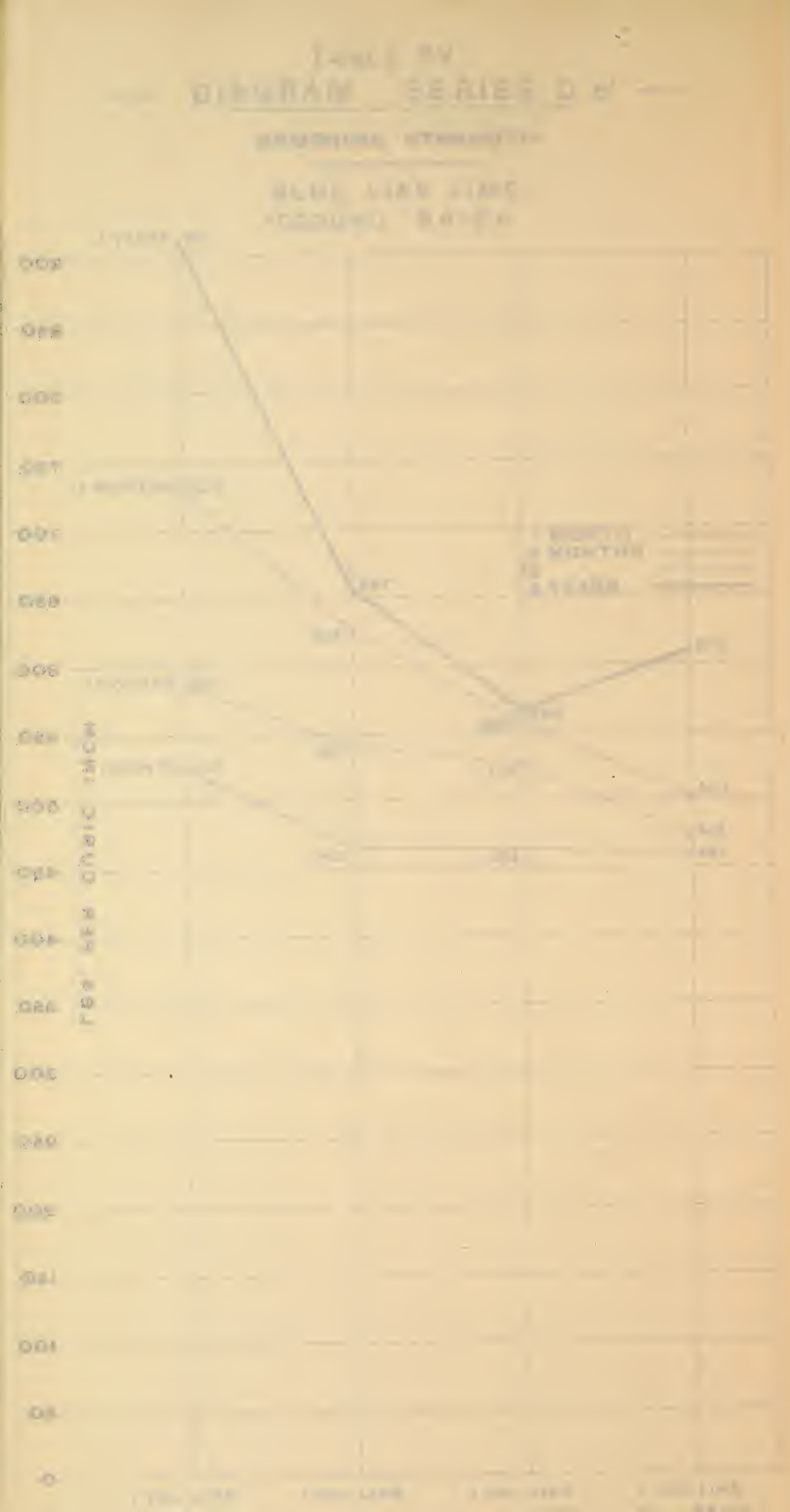
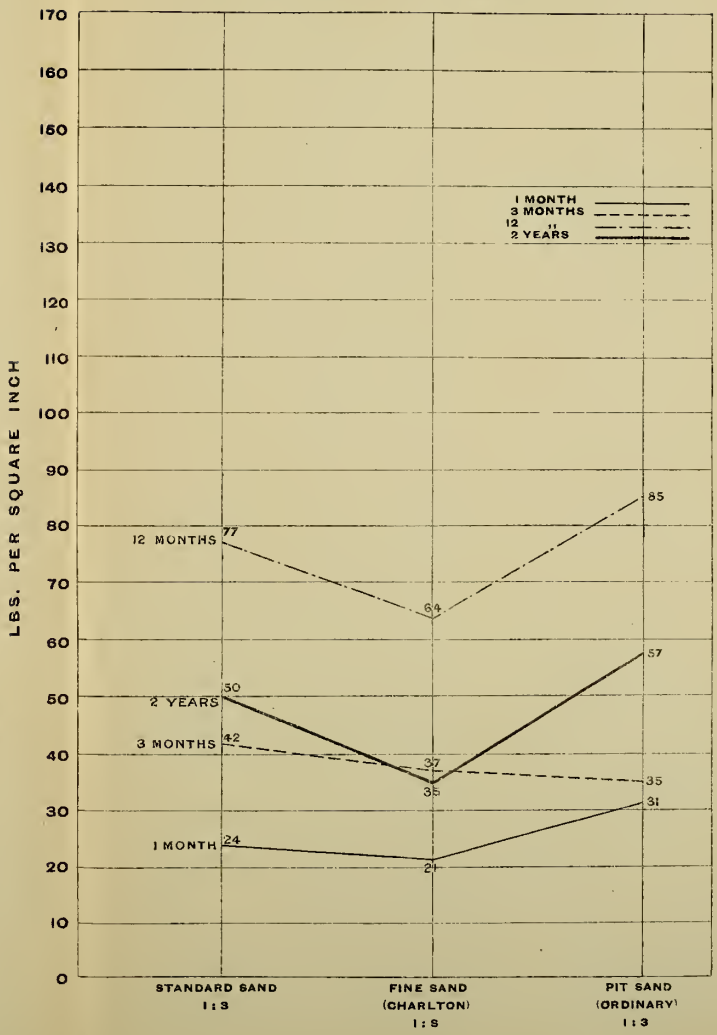


TABLE XVI.

DIAGRAM SERIES Da.

TENSILE STRENGTH.

WHITE CHALK LIME
+ AGGREGATE + 5% { RED / LONDON CLAY



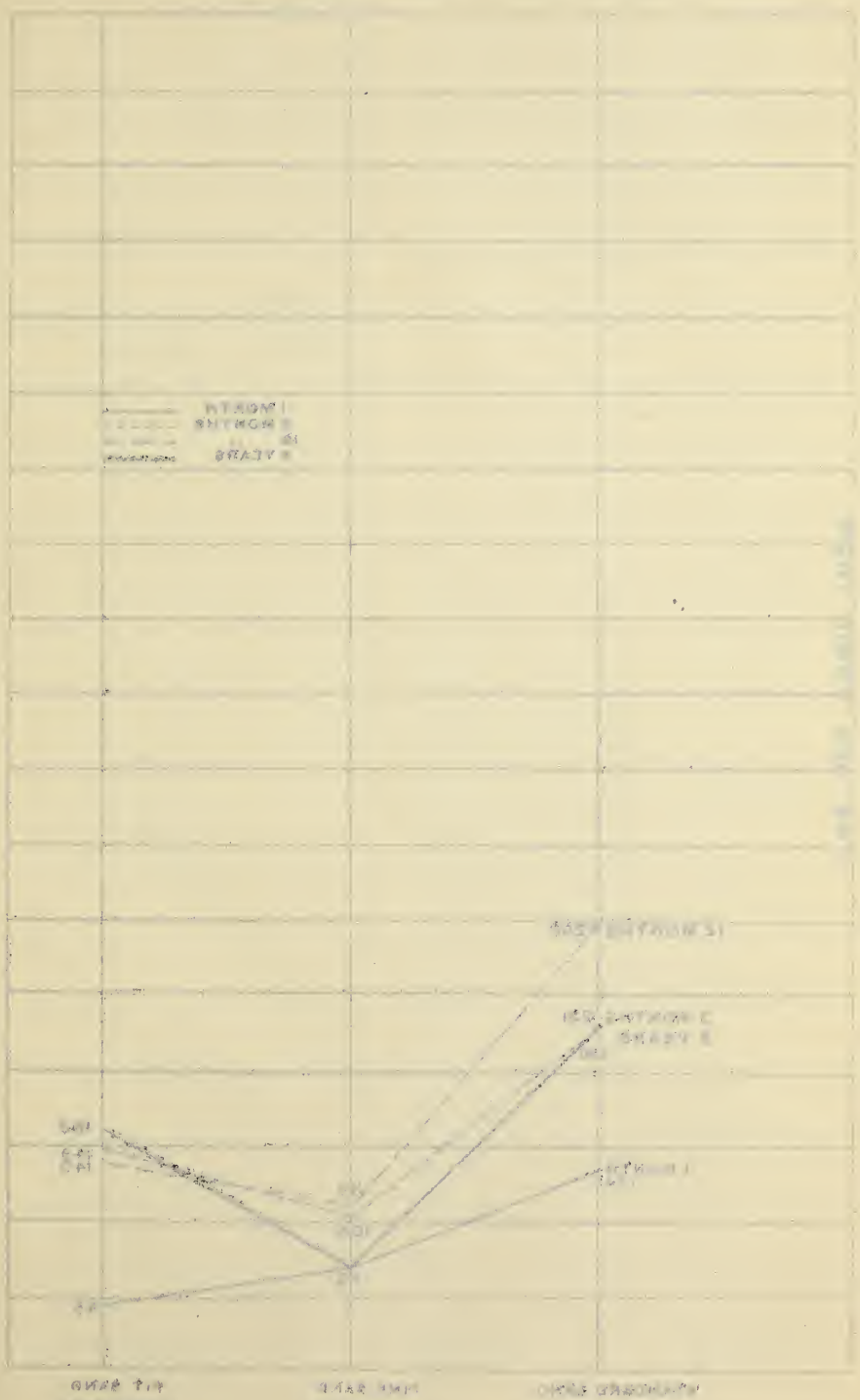
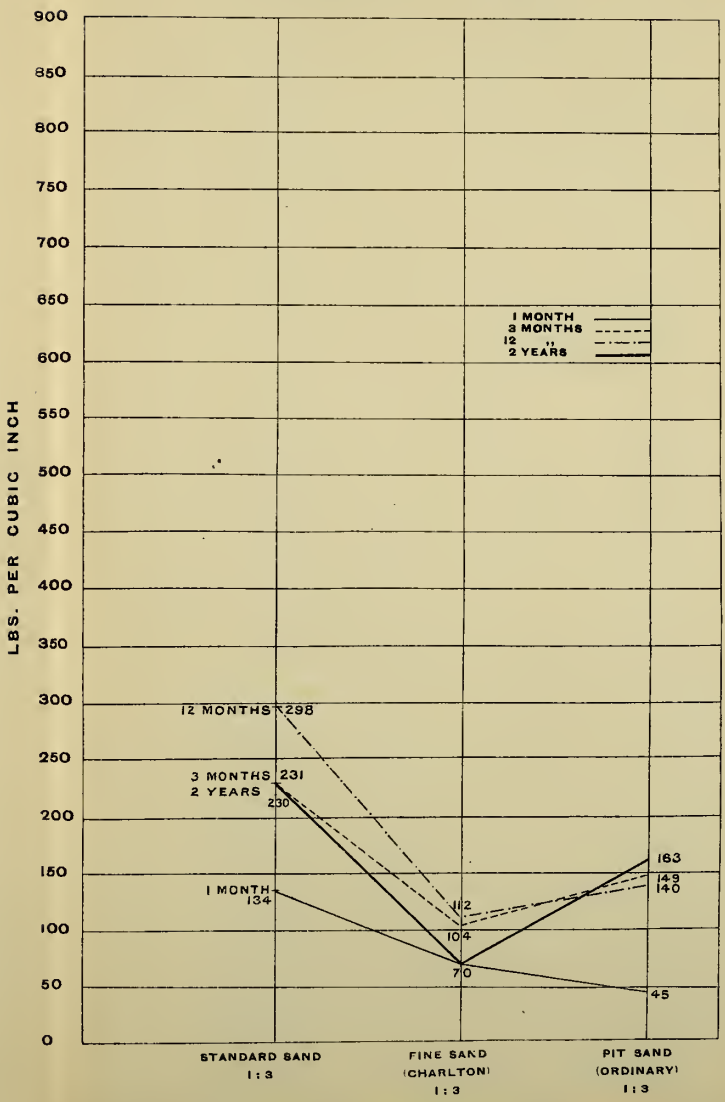


TABLE XVI.

DIAGRAM SERIES D. a.

CRUSHING STRENGTH.

WHITE CHALK LIME
+ AGGREGATE + 5% { RED / LONDON CLAY



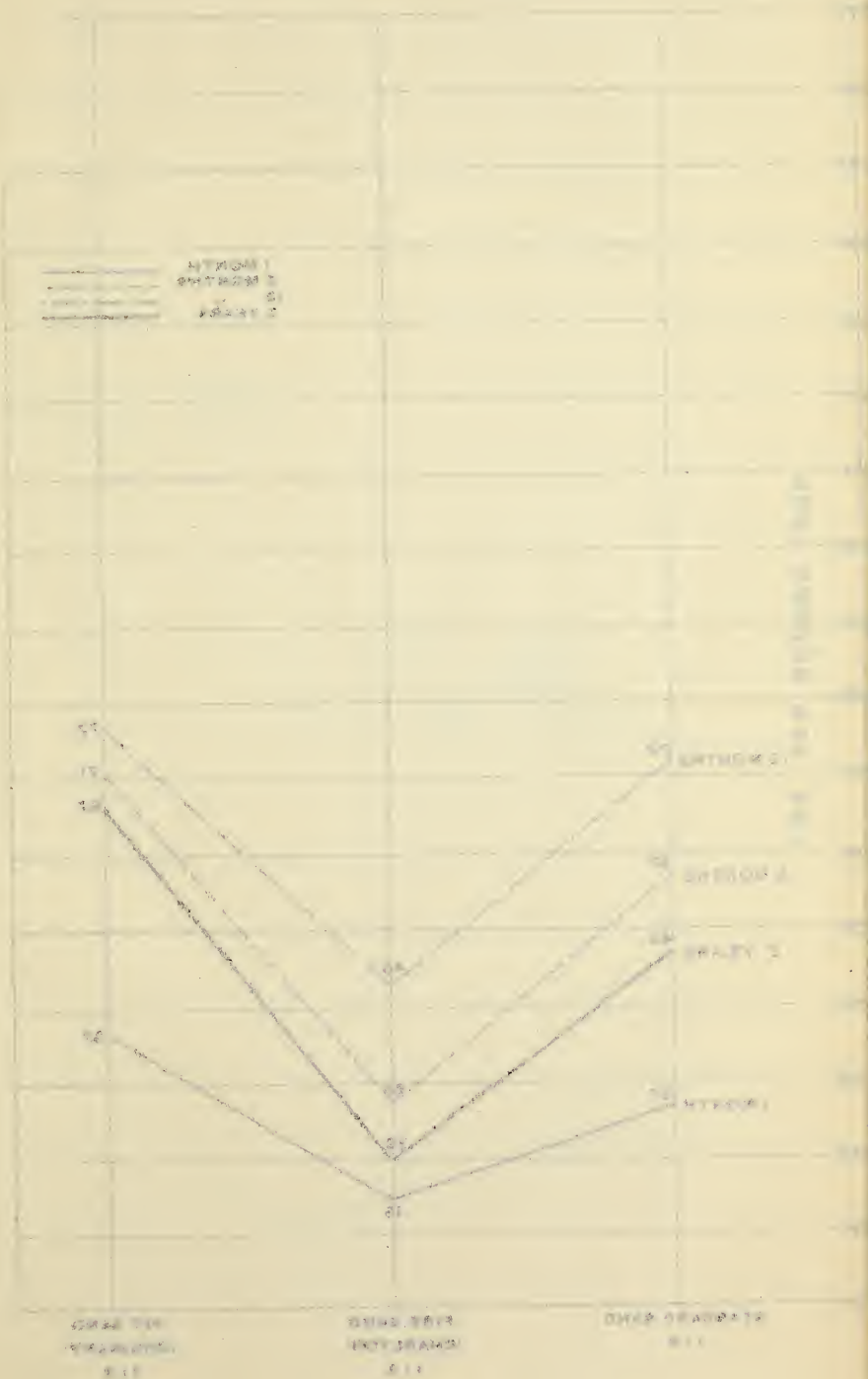


TABLE XVI

DIAGRAM SERIES D a

BRUSHING STRENGTH.

WHITE SHALE LIME

1 AGGREGATE + 3 [illegible]

TABLE XVI.

DIAGRAM SERIES Db.

TENSILE STRENGTH.

DORKING GREY STONE LIME
+ AGGREGATE + 5% {RED / LONDON CLAY

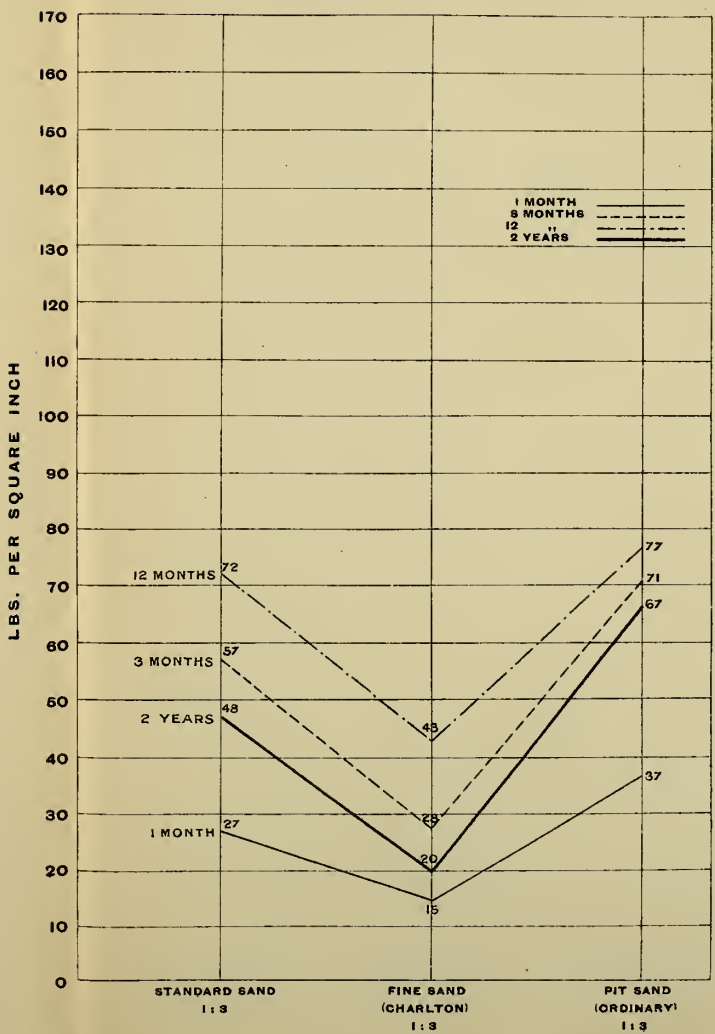


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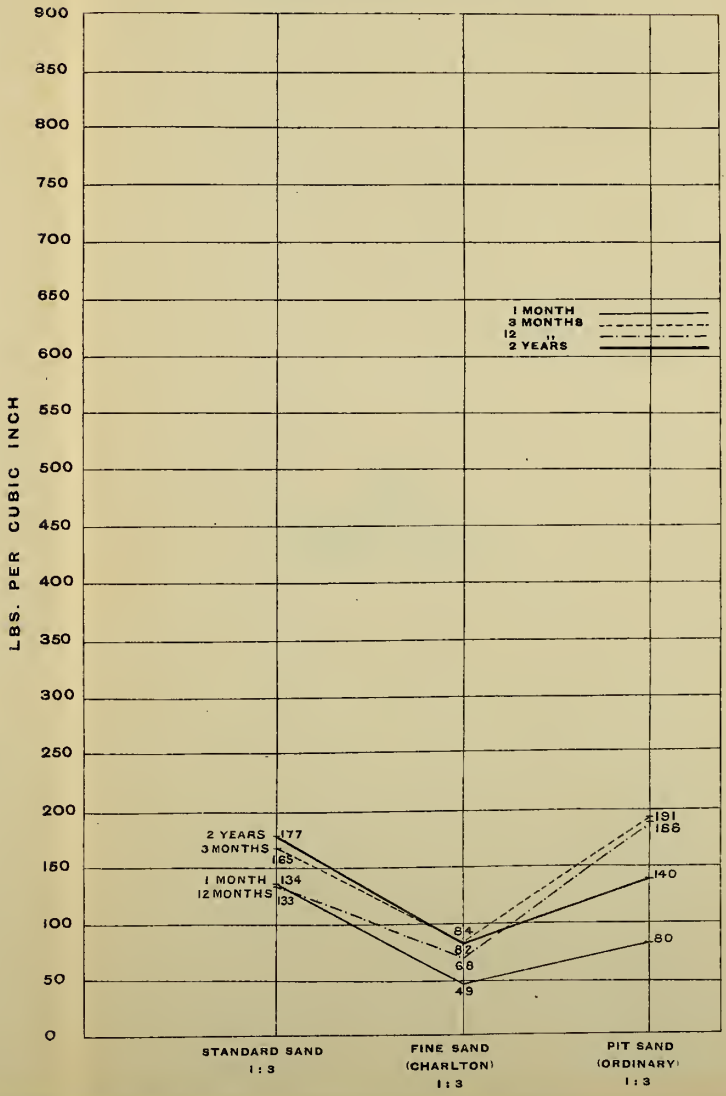
TABLE XVI.

DIAGRAM SERIES D 6!

CRUSHING STRENGTH.

DORKING GREY STONE LIME.
+ AGGREGATE + 5% { RED LONDON CLAY



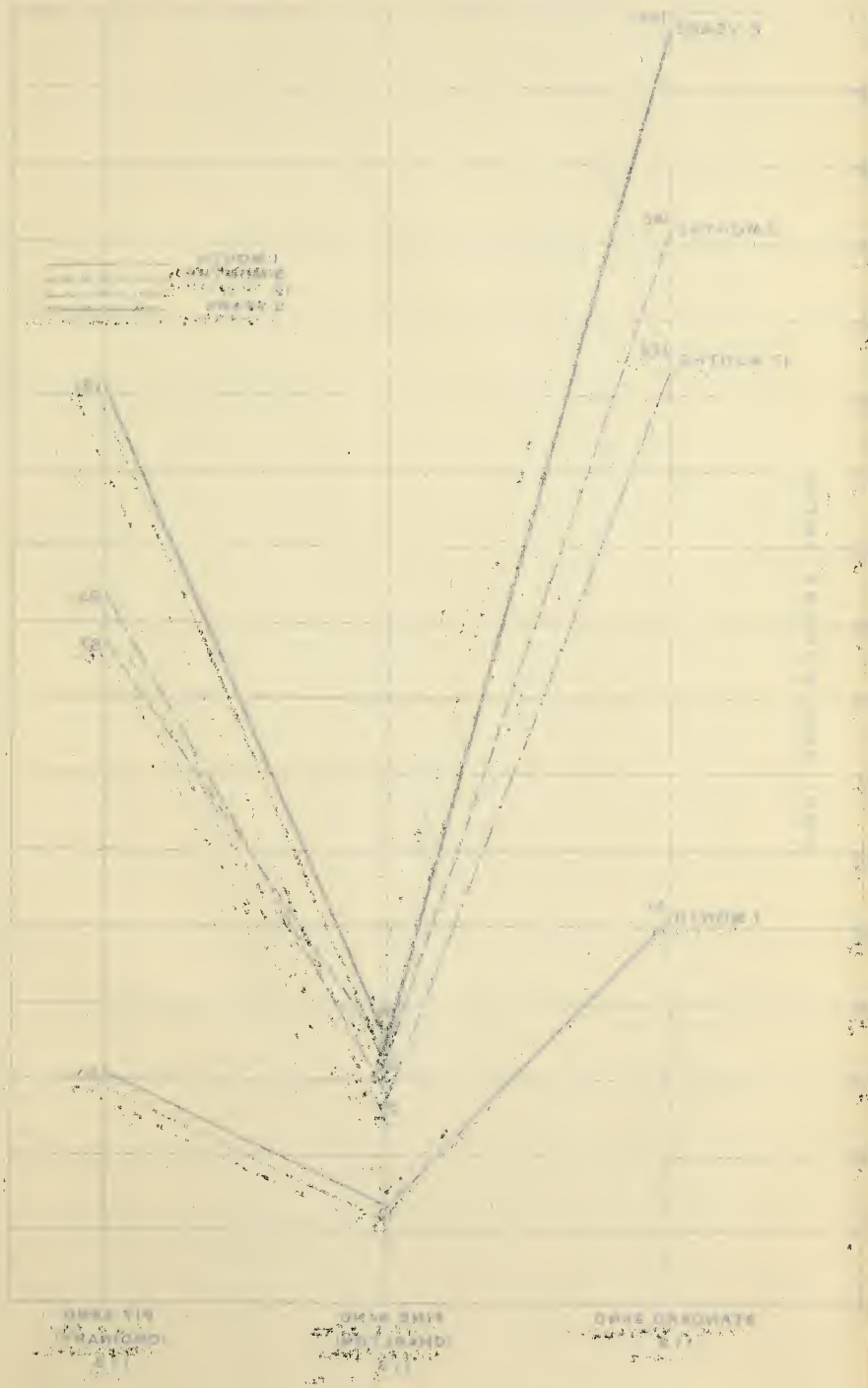


TABLE XII.

DIAGRAM SERIES D-W

CRUSHING STRENGTH

CURRING DRY STORE LIME

— AGGREGATE 1" SE.

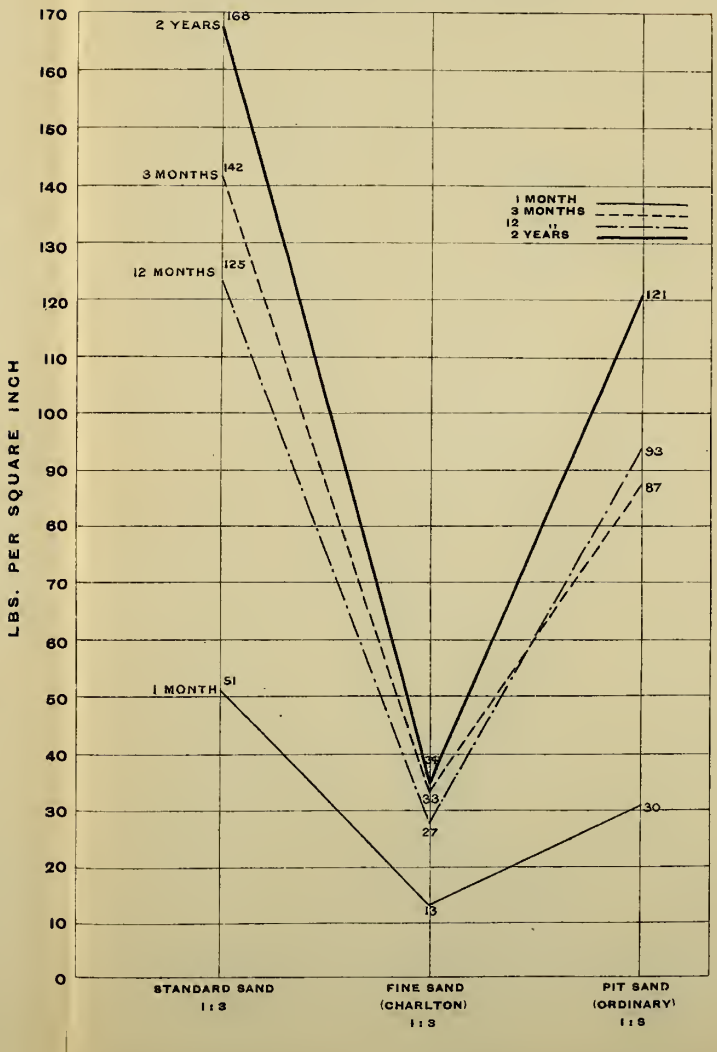
TABLE XVI.

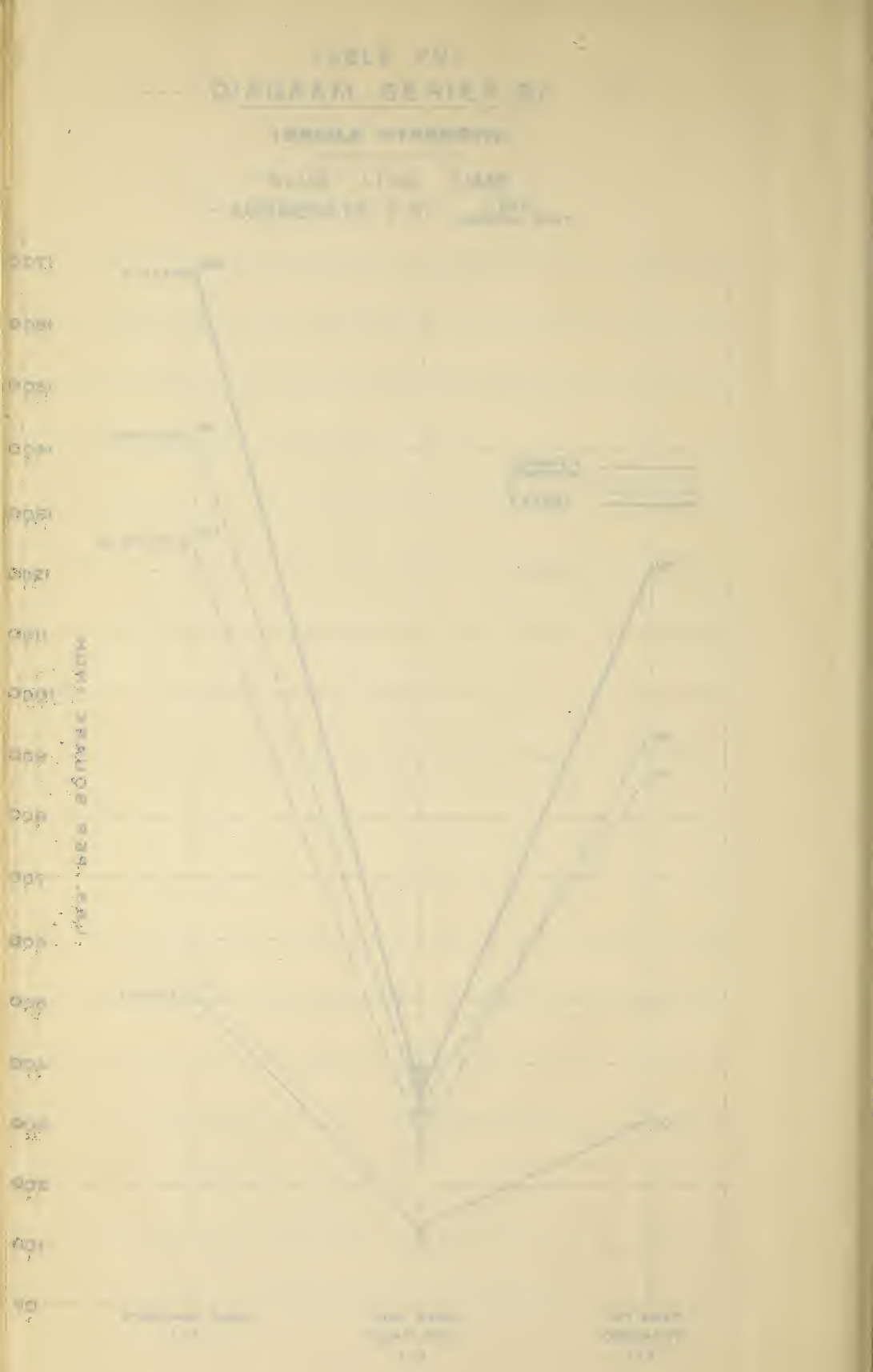
DIAGRAM SERIES Dc.

TENSILE STRENGTH.

BLUE LIAS LIME

+ AGGREGATE + 5% { RED / LONDON CLAY





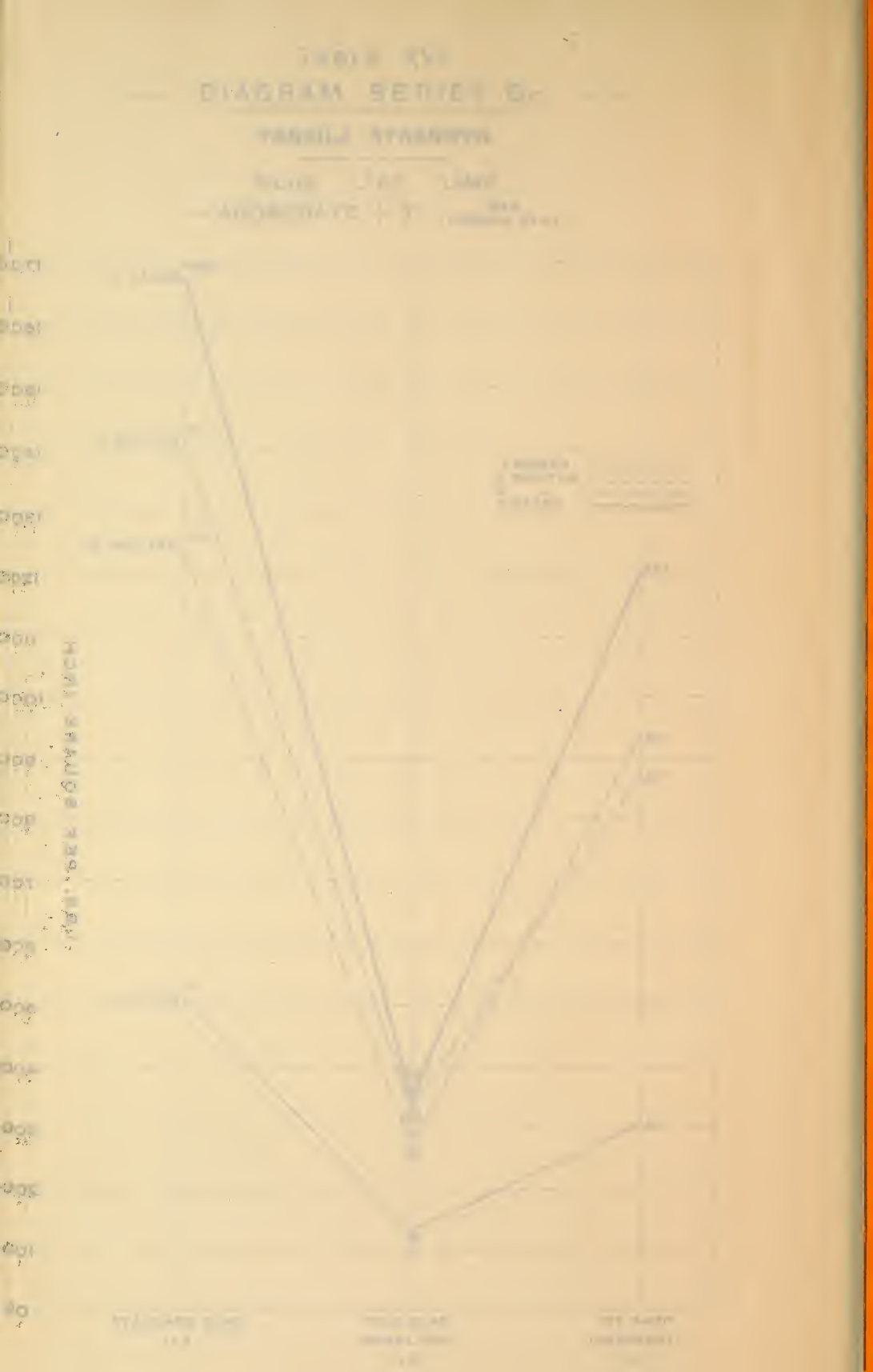
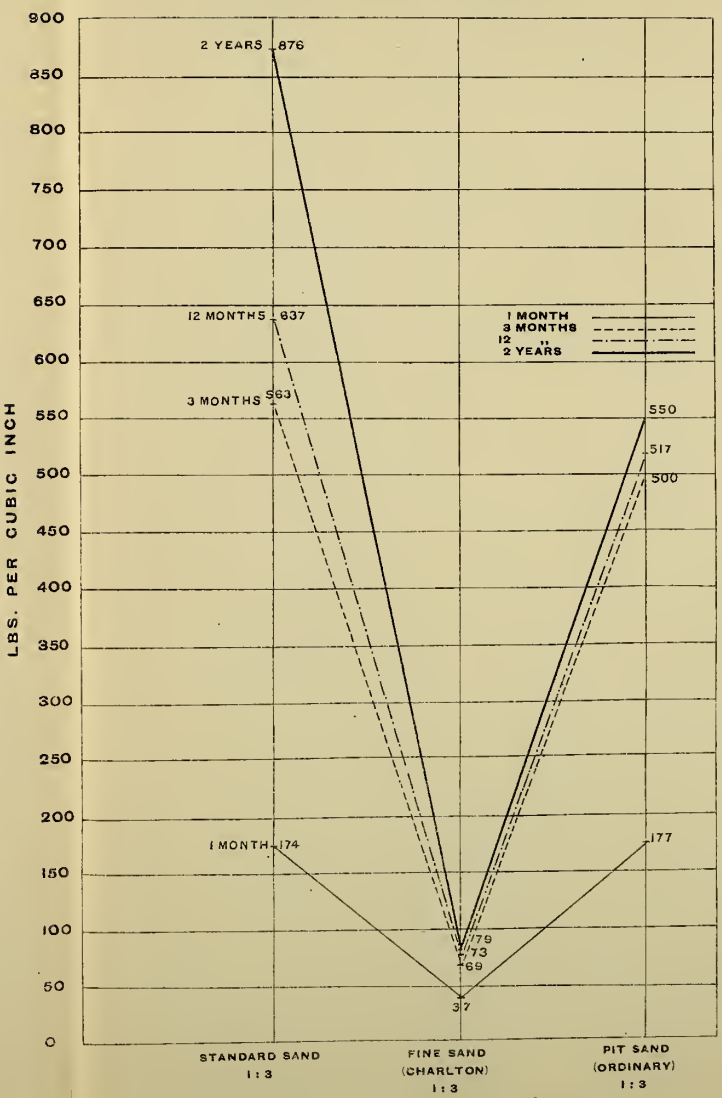


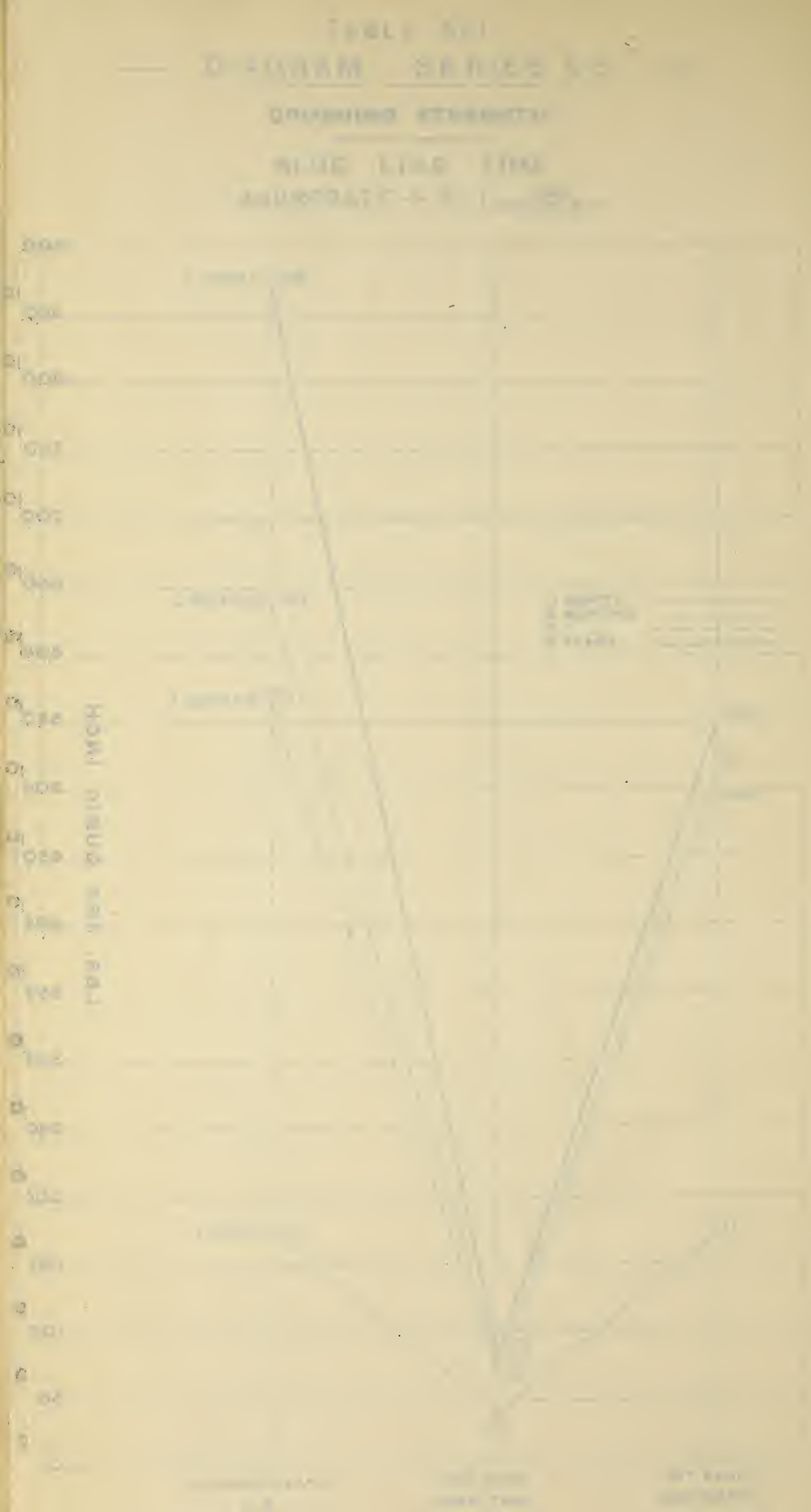
TABLE XVI.

DIAGRAM SERIES Dc!

CRUSHING STRENGTH.

BLUE LIAS LIME + AGGREGATE + 5% {RED / LONDON CLAY}





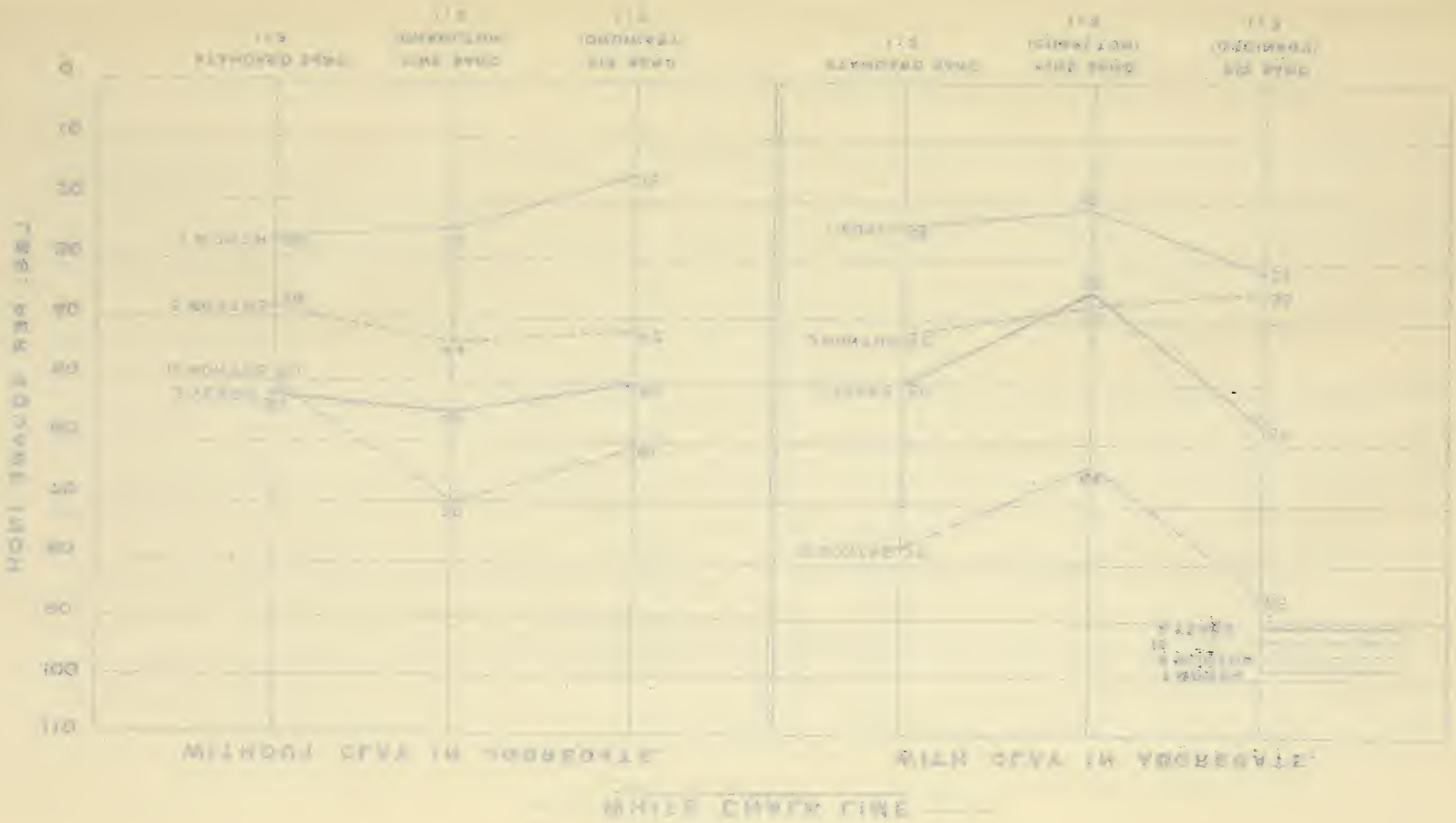


TABLE XVI

DIAGRAM SERIES C2

COUNTING STRENGTH

BLUE LIAS LIME

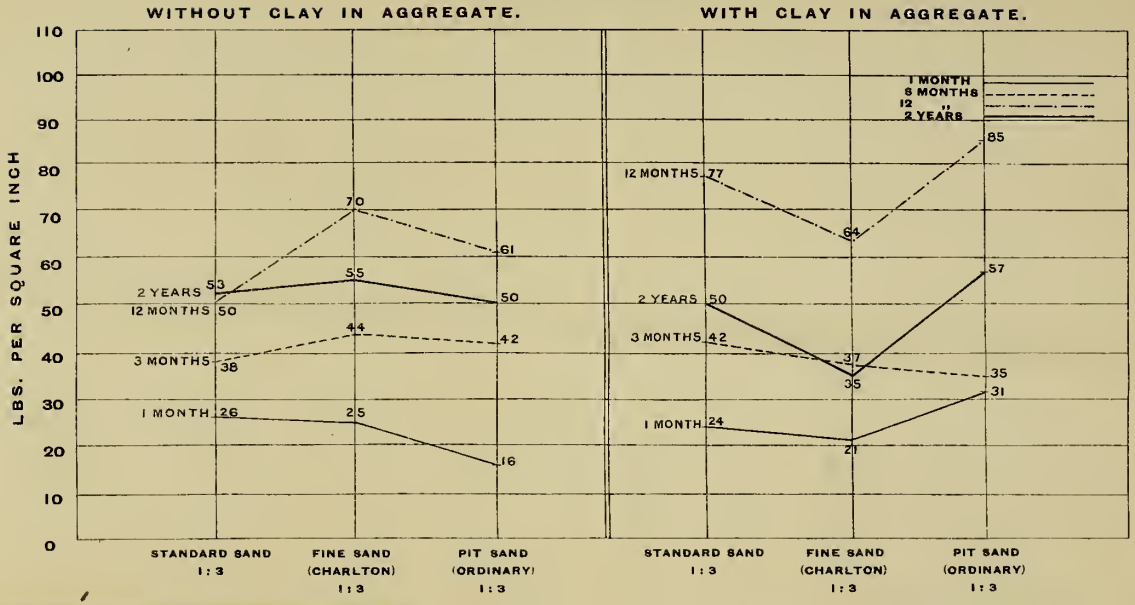
AGGREGATE = 2° [illegible]

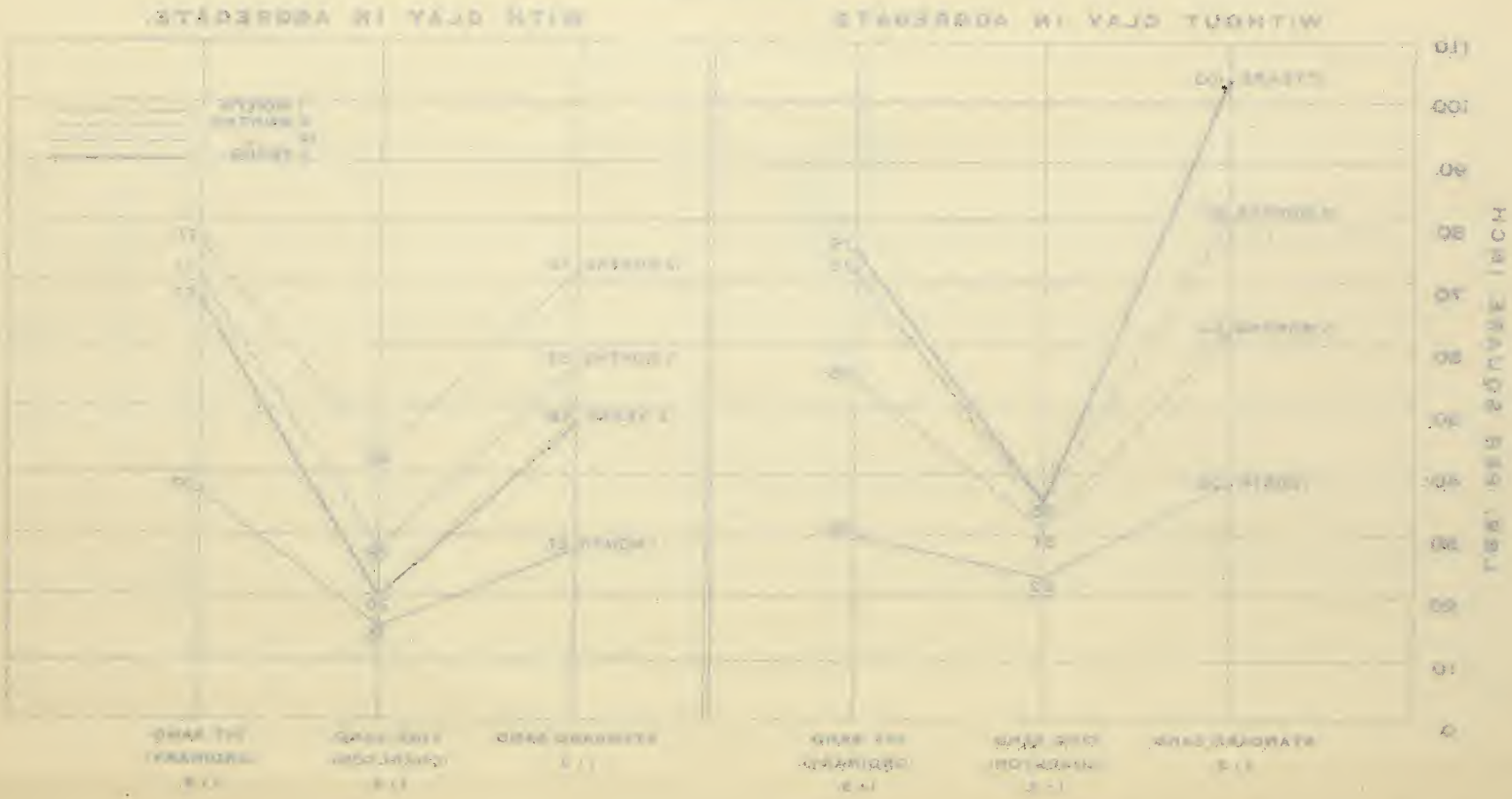
TABLE XVII.

DIAGRAM SERIES Ga.

TENSILE STRENGTH.

WHITE CHALK LIME





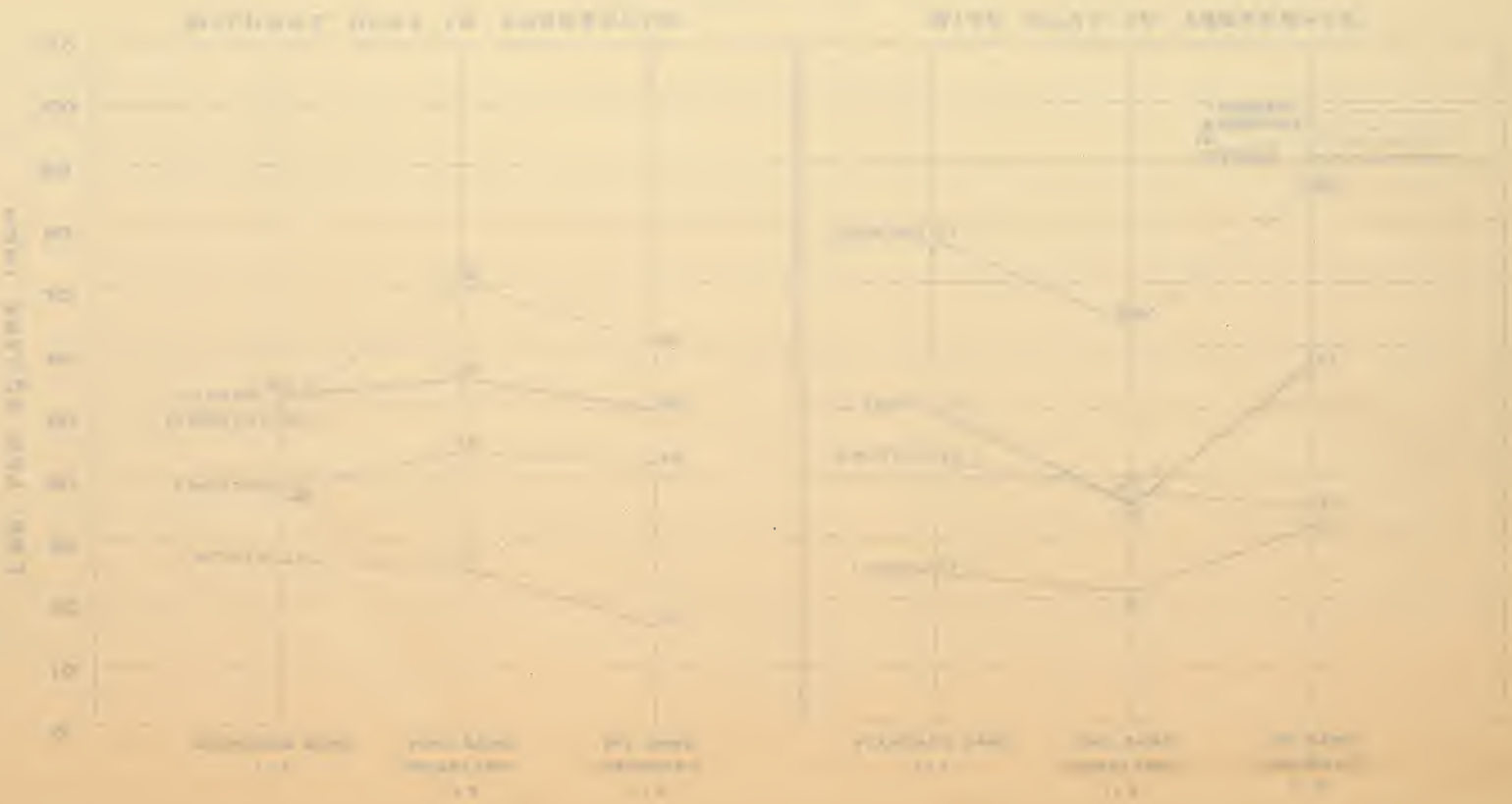
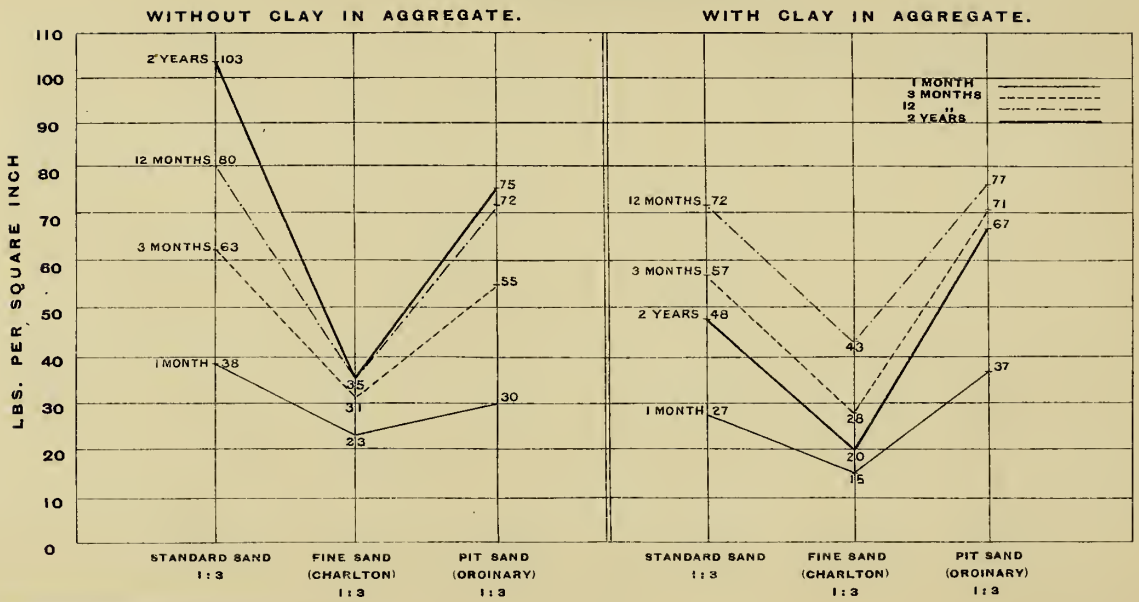


TABLE XVII.

DIAGRAM SERIES G b.

TENSILE STRENGTH.

DORKING GREY STONE LIME.



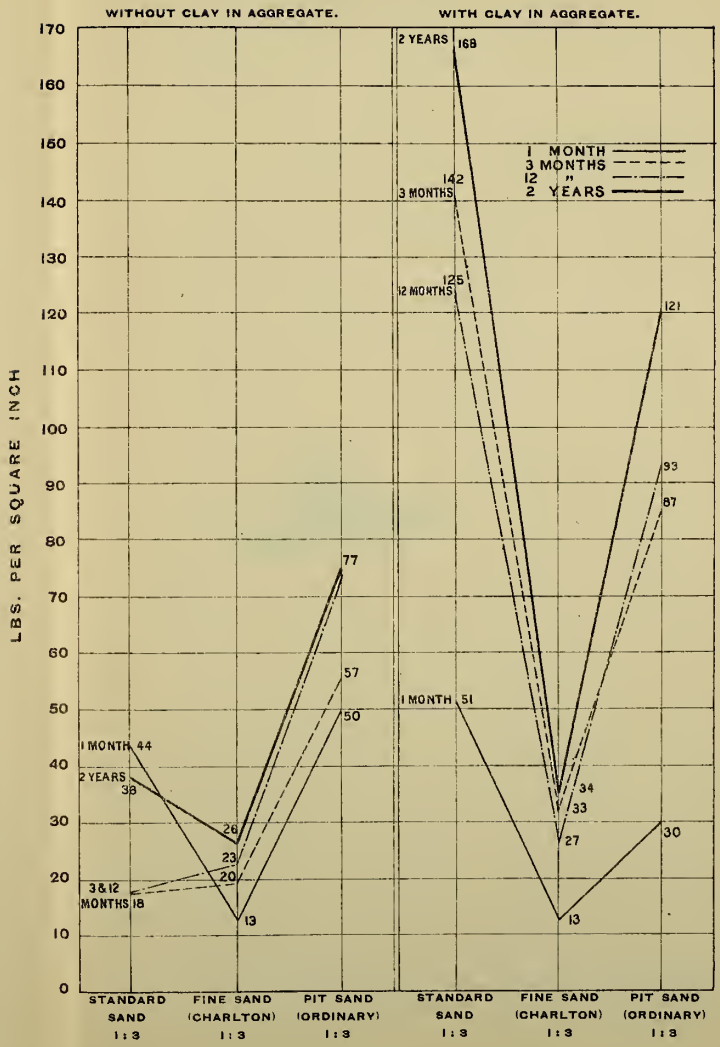
DIVCOWW - SENIER CP
LYOPS-WAIF
DOKS IN OREX STORE LINE
WITHOUT SLAT IN HORRORIC
WITH SLAT IN HORRORIC
LAB PER MILLIONS, INCH
100
90
80
70
60
50
40
30
20
10
0

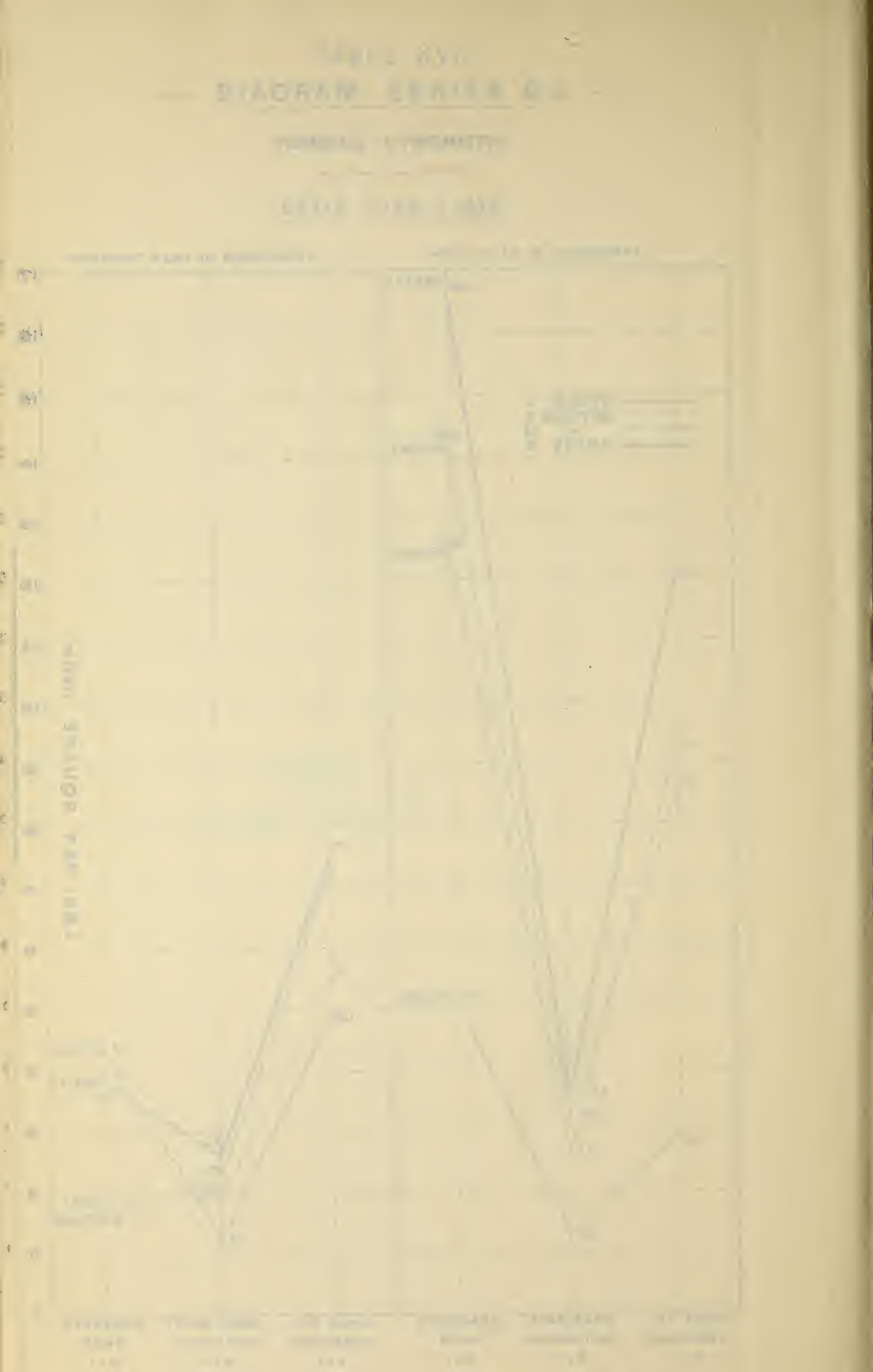
TABLE XVII.

DIAGRAM SERIES G.c.

TENSILE STRENGTH.

BLUE LIAS LIME.





1:3 (CHARLTON) 1:3 1:3 1:3

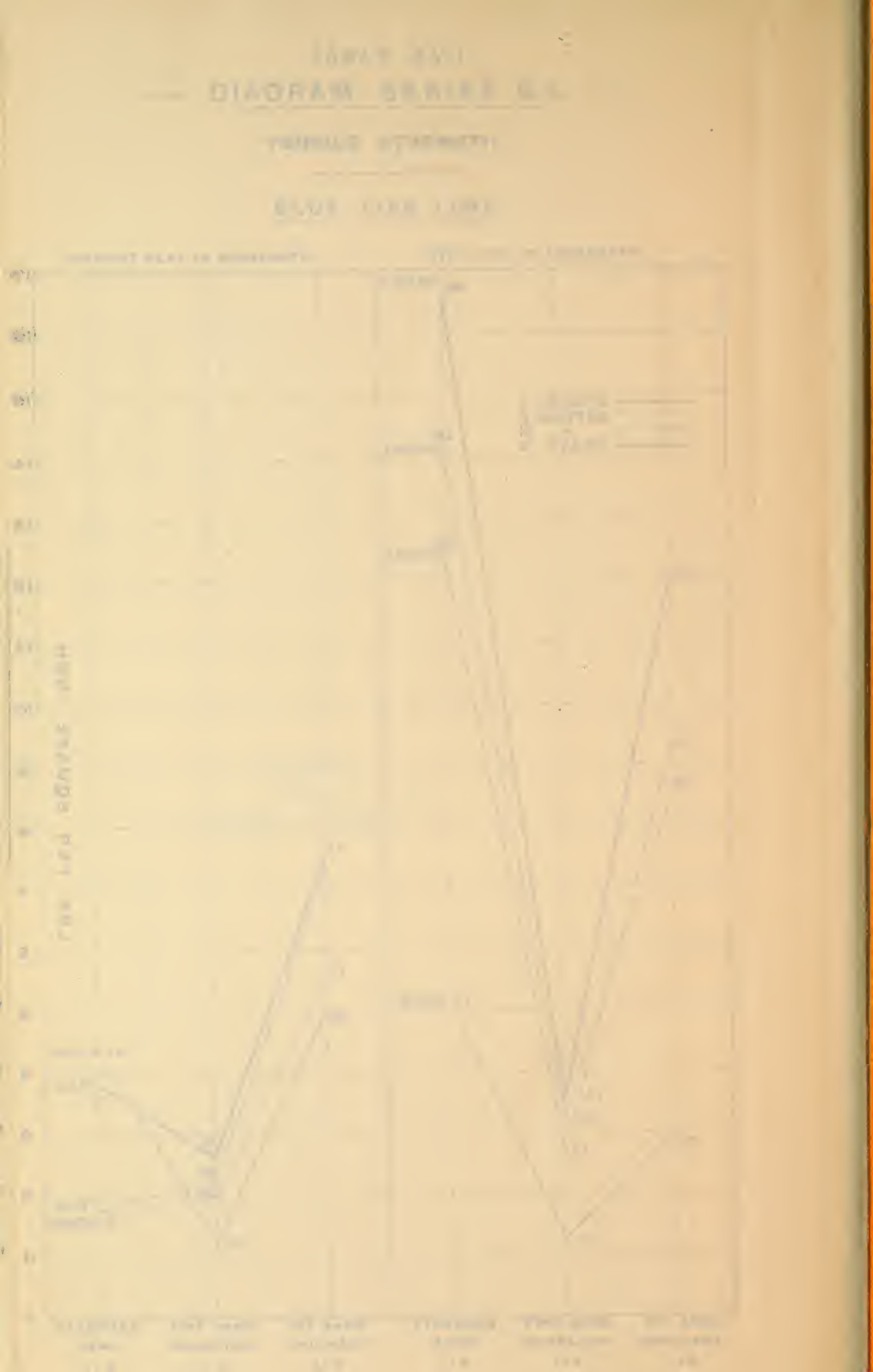


TABLE XVIII.

DIAGRAM SERIES G. a!

CRUSHING STRENGTH.

WHITE CHALK LIME.

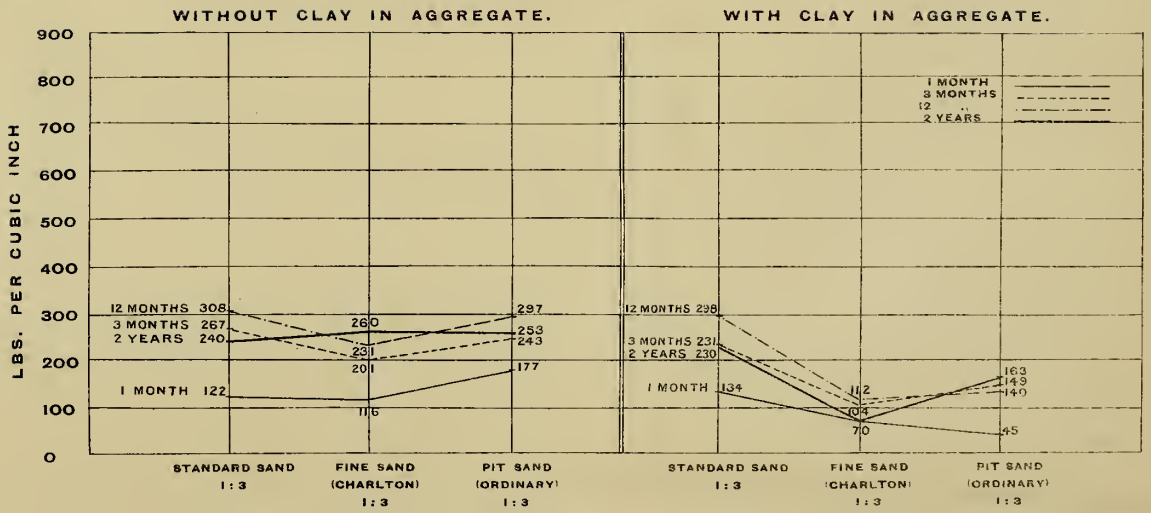
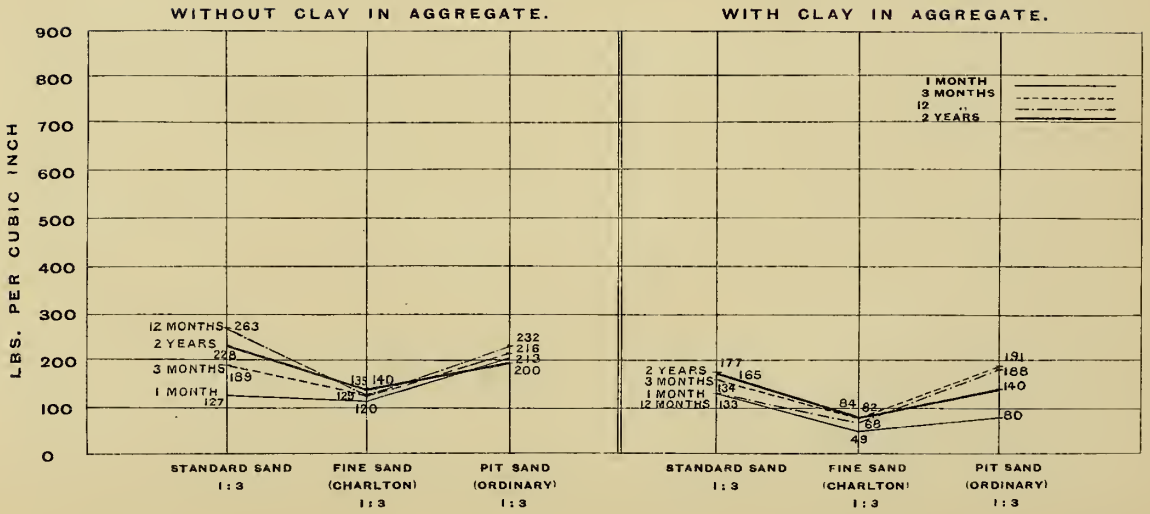


TABLE XVIII.

DIAGRAM SERIES G b!

CRUSHING STRENGTH.

DORKING GREY STONE LIME



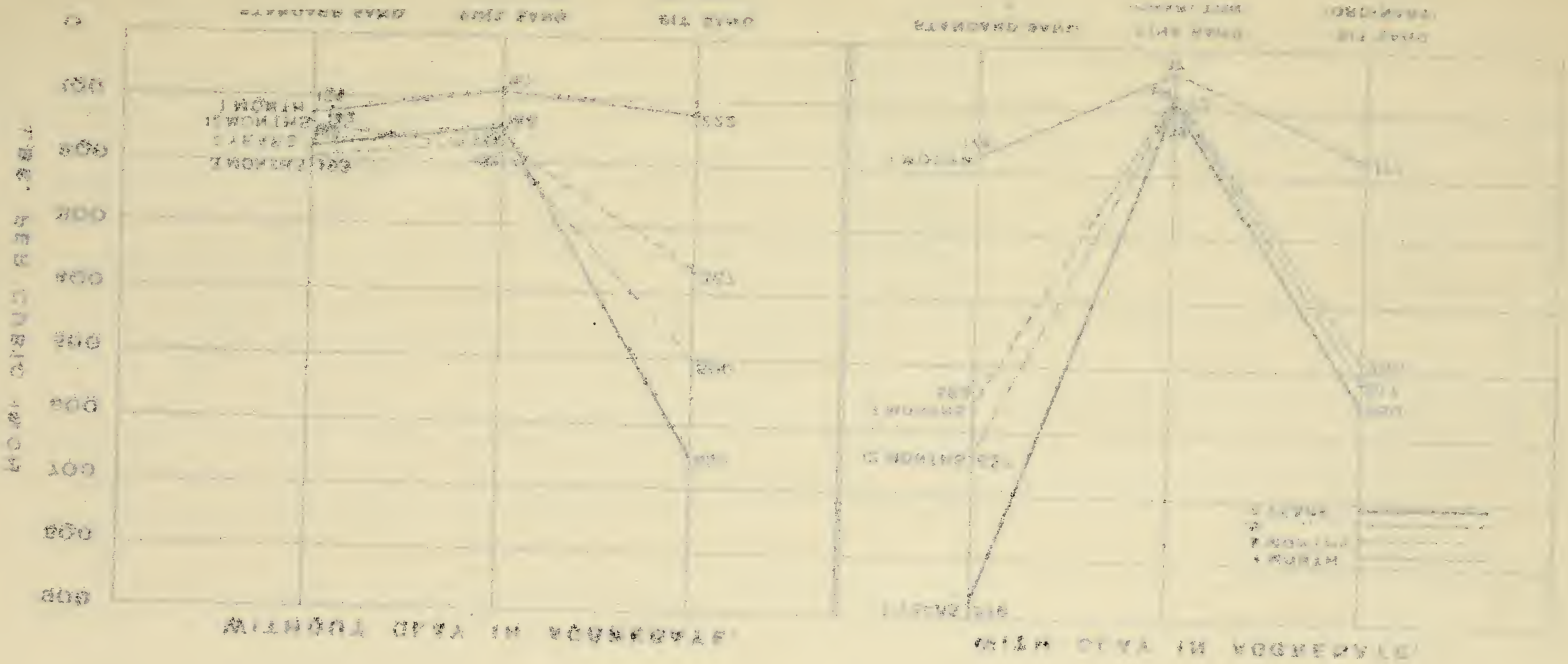
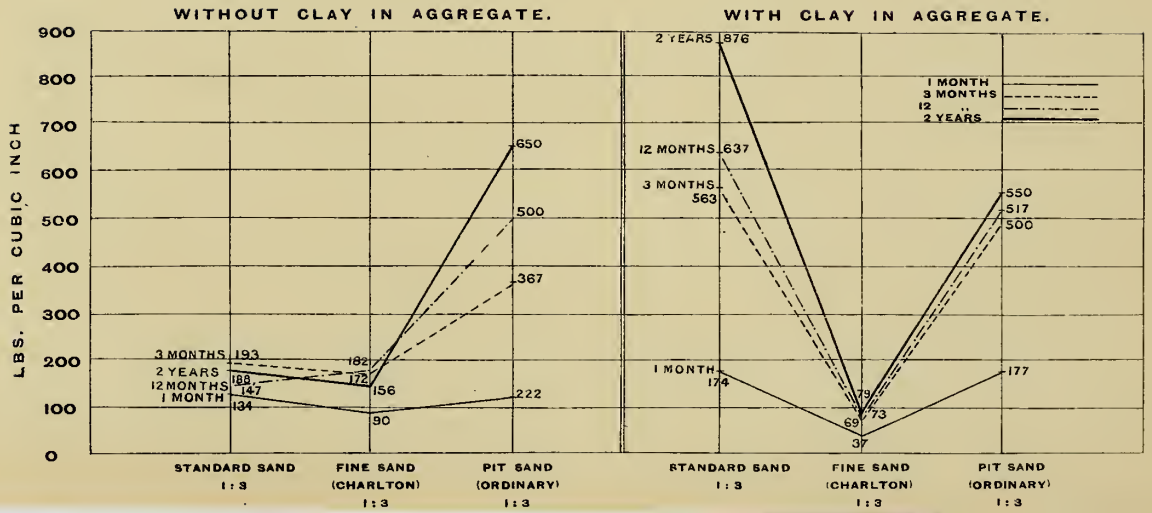


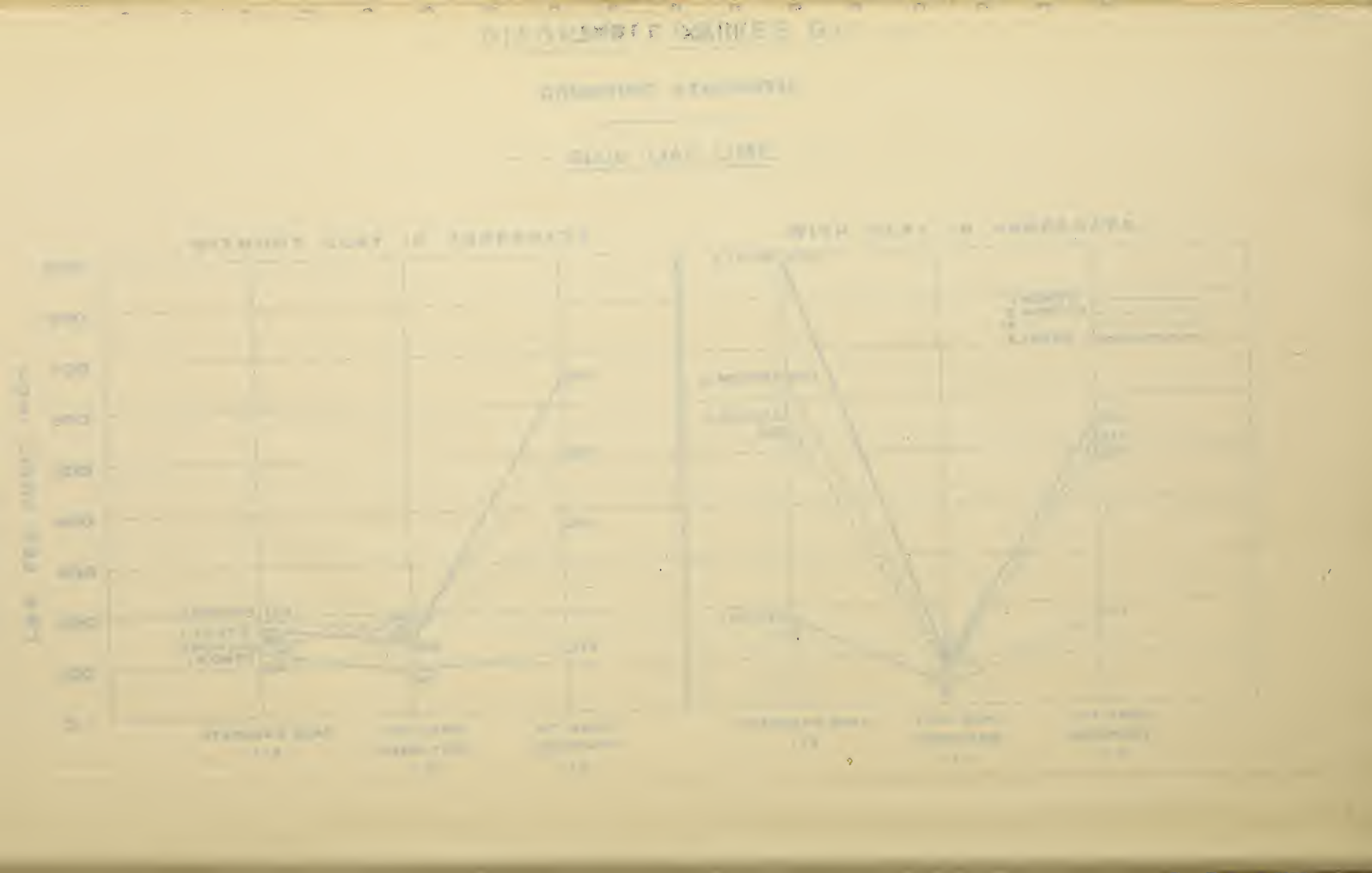
TABLE XVIII.

DIAGRAM SERIES G.c!

CRUSHING STRENGTH.

BLUE LIAS LIME.





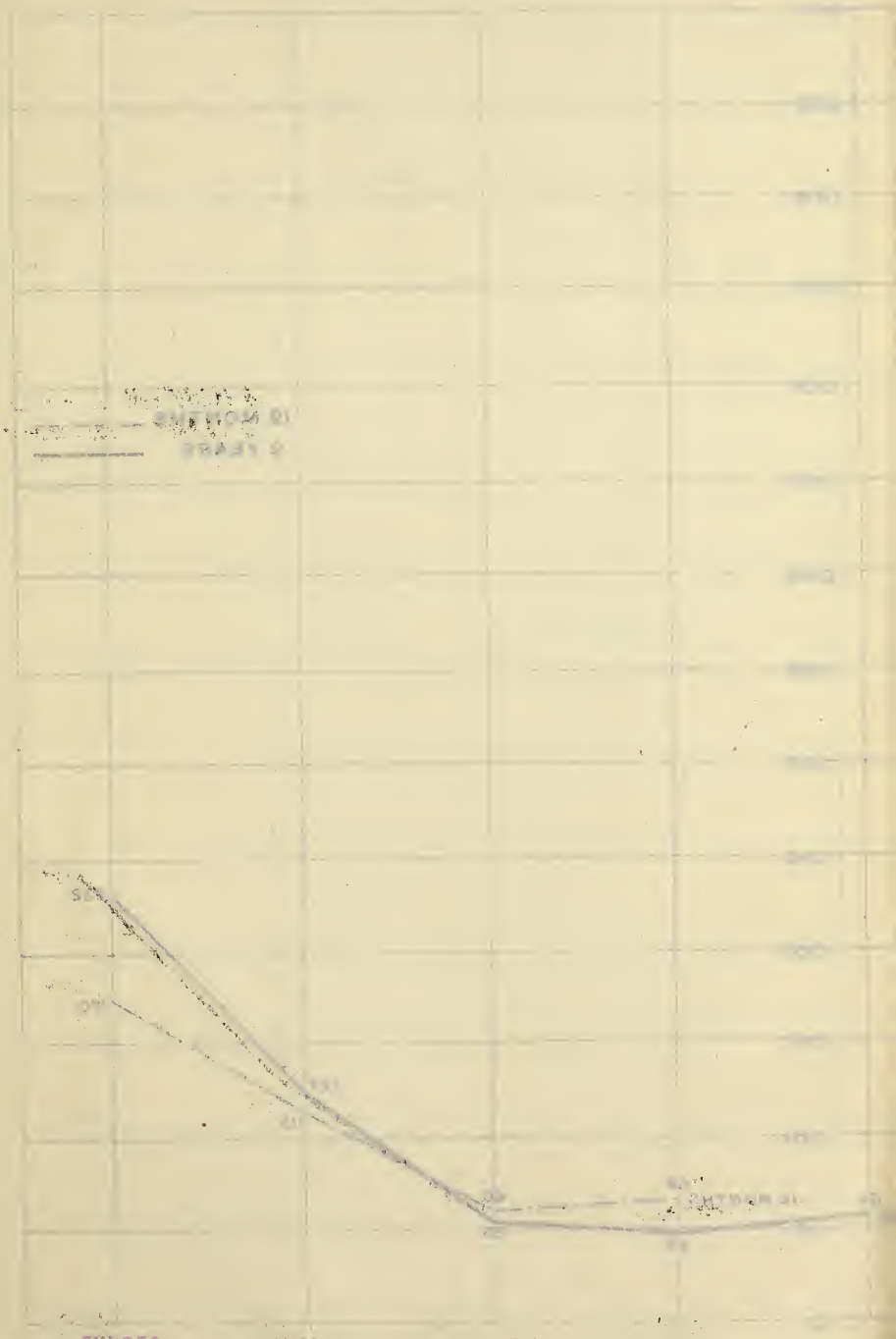


TABLE XIX.

DIAGRAM SERIES E.A.B.C.D.E.

ADHESIVE STRENGTH.

STOCK BRICKS BONDED WITH
DORKING GREY STONE LIME + AGGREGATE 1:3

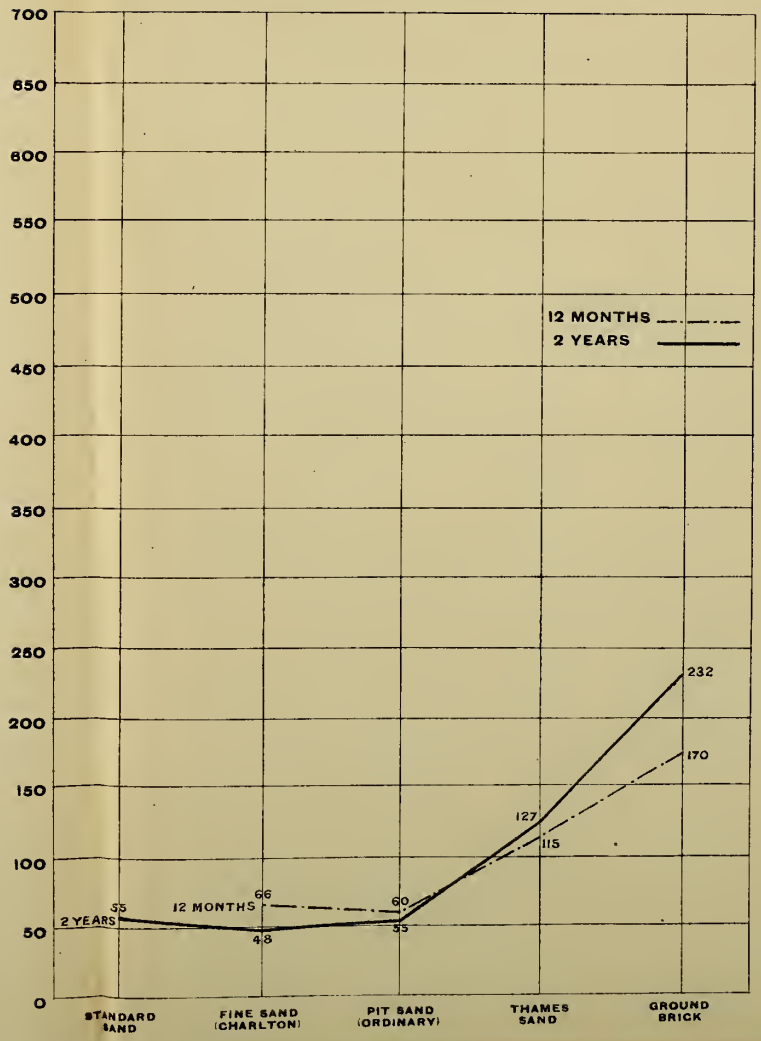
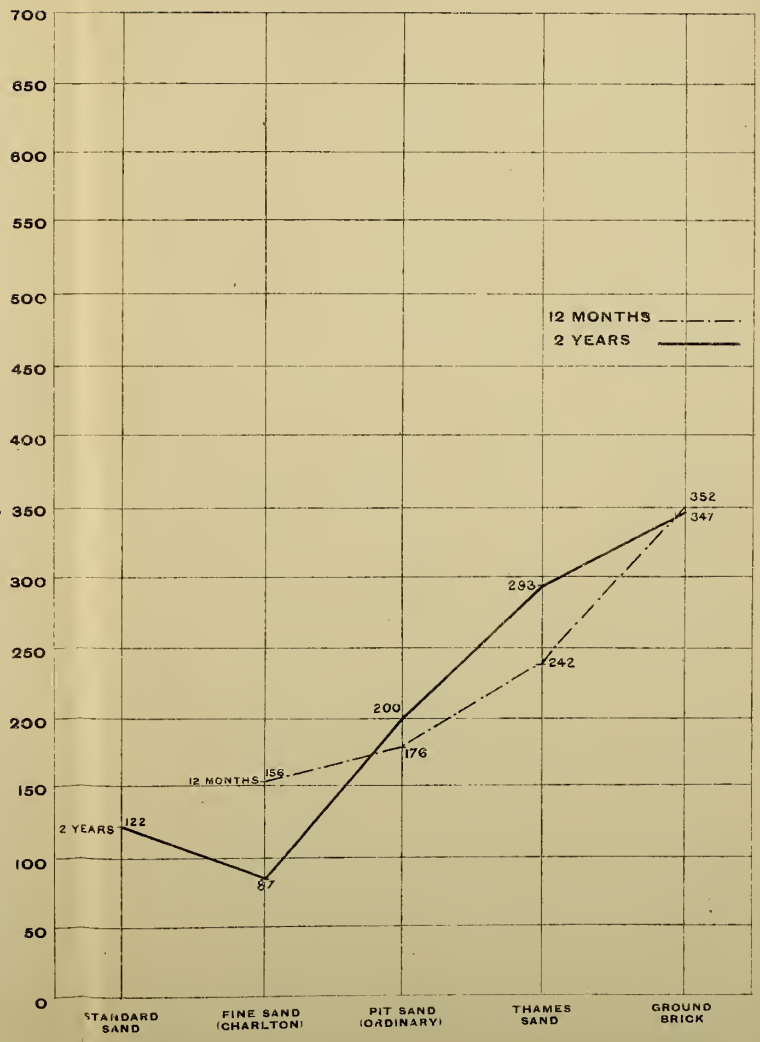


TABLE XIX.

DIAGRAM SERIES F.A.B.C.D.E.

ADHESIVE STRENGTH.

FLETTON BRICKS BONDED WITH
DORKING GREY STONE LIME + AGGREGATE 1 : 3



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